ENERGY, MINES & RESOURCES CANADA
CAPE BRETON COAL RES
CANMET
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SYDNEY, N. S.
File No. .....

REQ. NO. 4-9231

CONTRACT REPORT NO. OGT 84-00390

UNDERGROUND MINE FIRE CONTROL SEMINARS

PREPARED FOR

DEPARTMENT OF SUPPLY AND SERVICES CANADA

SUBMITTED BY

ASSOCIATED MINING CONSULTANTS LTD
AND
JOHN P. L. BACHARACH AND ASSOCIATED LIMITED

39 pp

OCTOBER 1984

AR-89

AMCL

UNDERGROUND MINE FIRE CONTROL SEMINARS

PRESENTED BY

ASSOCIATED MINING CONSULTANTS LTD
WITH
JOHN P.L. BACHARACH & ASSOCIATES LIMITED

MICROMEDIA

WORK ON THIS PROJECT WAS CONDUCTED UNDER THE AUSPICES OF THE CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY, ENERGY MINES AND RESOURCES, CANADA. (START PROGRAM).

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AMCL

AMCL Associated Mining Consultants Ltd.

6th Floor, 926 - 5 Avenue S.W., Calgary, Alberta T2P 0N7
Tel: (403) 264-9496 Telex: 03 821201

October 17, 1984

FILE: 0302-PB37

Department of Energy, Mines and Resources
Cape Breton Coal Research Laboratory
CANMET
210 George Street
SYDNEY, Nova Scotia
B1P 1J3

Attention: D. Bruce Stewart, P.Eng.
Manager

Dear Sirs:

Re: Underground Mine Fire Control Seminars
DSS File No. 07GT.23440-4-9231

We take pleasure in submitting our final report on the seminars presented across Canada on the subject of Underground Mine Fire Control.

We would like to thank the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada, for sponsoring the seminars and for their advice and guidance during their execution.

Respectfully submitted,

ASSOCIATED MINING CONSULTANTS LTD.

Alan L. Craven, P.Eng.
Manager

ALC:ms

AR-89

UNDERGROUND MINE FIRE CONTROL SEMINARS

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UNDERGROUND MINE FIRE CONTROL SEMINARS

1. INTRODUCTION

Following submission of the report entitled **'Underground Coal Mine Fire Control With Inerting Systems - A Study'**, (DSS File No. 23SQ.23440-3-9035), by Associated Mining Consultants Ltd., it was suggested that the information contained in it should be disseminated to the Canadian mining industry through a series of Seminars.

Associated Mining Consultants Ltd. were awarded a contract (DSS File No. 07GT.23440-4-9231) to organize the seminars.

2. LOCATION

Four seminars were held at the following locations:

September 17, 1984	Sydney, Nova Scotia CBDC Human Resource Centre
September 19, 1984	Sudbury, Ontario Northbury Hotel
September 24, 1984	Vancouver, B.C. Holiday Inn, Harbourside
September 25, 1984	Calgary, Alberta Holiday Inn, Downtown.

3. NOTIFICATION

Brochures describing the seminar content, speakers, dates and locations, were prepared in English and French (Figures 1 and 2).

Copies were mailed to some 1100 organizations and individuals. Sources of mailing lists included:

Coal Association of Canada Directory
Canadian Mines Handbook
Engineering and Mining Journal Directory
Coal Mining Research Centre
Canadian Institute of Mining and Metallurgy

In addition, personal contact was made with many organizations and individuals believed to have a direct interest in the seminars.

Time constraints between award of contract and the dates of the seminars that had to recognize the availability of the Key Speakers prevented advertising in the technical press.

4. ORGANIZERS

The seminars were organized and administered by the following personnel:

Alan L. Craven	Associated Mining Consultants Ltd.
John P.L. Bacharach	John P.L. Bacharach & Associates Limited
J. Maxine Swann	Associated Mining Consultants Ltd.
Della Giacomuzzi	John P.L. Bacharach & Associates Limited

Ravi Philar, Technology Marketing Officer, Office of Technology Transfers, CANMET, gave significant direction as representative of the funding agency.

D. Bruce Stewart, Manager, Cape Breton Coal Research Laboratory, CANMET, provided invaluable support prior to and during the seminars, which he attended as the CANMET representative. His presence and advice contributed greatly to the success of the seminars.

5. SPEAKERS

Four speakers were engaged to prepare and present technical papers, namely:

Gordon Jolliffe	Head of Mine Rescue, Yorkshire District National Coal Board, UK.
Franz-Joseph Kock	Chief of Mine Rescue Centre Essen, West Germany
Claude Froger	Assistant Director Cerchar, Charbonnage de France
John P.L. Bacharach	President John P.L. Bacharach & Associates Limited

Claude Froger replaced Jacques Lux, who was unavailable.

The invited Speakers who are acknowledged experts of international stature, contributed significantly to the overall credibility of the seminars. In addition, they provided participants with access to their very extensive practical experience of fire control. We are not aware of a group of experts of this calibre having delivered any seminar on fire control in North America prior to the series under review.

6. PROGRAM

The basic program for each of the seminars was the same, but the detailed content was modified to suit the particular concerns of the participants. For instance, emphasis at the Sydney Seminars was on coal mines, while the emphasis at Sudbury was on metal mines.

The program is given below:

8:30	- 8:45	Welcome/Introduction - Bruce Stewart
8:45	- 10:15	Principles and Practice of Mine Fire Combat Gordon Jolliffe
10:15	- 10:30	Coffee
10:30	- 12:00	Operations of the German Mine Rescue/Fire Fighting Service Franjo Kock
12:00	- 1:15	Lunch
1:15	- 2:45	Fire Combat Experience in French Underground Mines Claude Froger
2:45	- 3:30	Fire Control with Inerting for Canadian Underground Mines John Bacharach
3:30	- 3:45	Coffee
3:45	- 4:30	Discussion

7. HANDBOOK

A handbook was prepared covering the topics discussed by the speakers. This was distributed to each of the participants and a copy is attached as Appendix A.

8. ATTENDANCE

The following numbers attended the seminars, in addition to the organizers and speakers:

	Registered	Complimentary	Students	Total
Sydney	31	8	10	49
Sudbury	23	2	-	25

	Registered	Complimentary	Students	Total
Vancouver	10	2	-	12
Calgary	31	6	-	37
	95	18	10	123

The complementary attendees were CANMET staff plus a Charbonnage de France representative accompanying Claude Froger who registered at the first seminar but attended all four.

The registrants represented a substantial cross-section of the Canadian mining industry and all the major coal companies and most of the large underground non-coal mining companies were represented .

A breakdown of the organizations represented is given in Table 1. Five coal mining companies and 10 metal and non-metal mines were represented. Three Universities or research establishments took part. A total 11 Federal and Provincial authorities sent delegates, while 7 suppliers of equipment or gaseous products attended. Three consulting organizations sent representatives. Detailed participant lists for each seminar are attached as Appendix B.

9. TECHNICAL CONSIDERATIONS

The seminar format provided opportunities for audience participation after each session and at the end of the day's program.

A wide range of points were raised by the participants relating to areas of interest including the following:

- reserve requirement
- ventilation during a fire incident
- choice of fire control technique
- methods of assessing a fire incident

- explosion risks
- method of re-entering a fire area
- role of Government Agencies
- when to use inerting
- relative merit of different inerting media
- services available from industrial gas suppliers
- communications during a combat action
- controlling a major incident
- planning for handling fire incidents
- differences between coal and non-coal situations
- use of self rescuers
- pros and cons of refuge chamber
- value of exchange of experience and know-how throughout the industry
- research objectives related to fire control
- centralized holding of major emergency equipment.

These topics and many others were addressed by one or more of the speakers, thus providing information and answers related to specific local needs.

10. CONCLUSIONS

The seminars' attendance were less than projected, probably due to budget restrictions applied to industry and Government Agencies. Nevertheless, the seminars attracted people from across Canada from the majority of the Provinces where underground mining is an important industry and the information and ideas generated will undoubtedly be disseminated far beyond the actual attendees.

Should a serious fire develop anywhere in Canada, it is now highly probable that one or more of the people involved, whether from industry, Provincial or Federal Government, will have had access to the technology transferred by the seminars, either directly, from discussions with colleagues or from reviewing the seminar handbook and will be significantly better equipped to deal effectively with the emergency.

If just one fire is handled more expeditiously, the involvement in the seminars could be fully vindicated in terms of reduced human suffering and lessened economic consequences.

The degree of success of the seminars is hard to evaluate quantitatively, but subjectively is indicated by the number of participants who stated that it was the best mining technology transfer occasion they had ever attended. It undoubtedly contributed to enhancing the industry's view of CANMET activities by demonstrating that a study such as that on inerting, provides carefully researched solutions to the real problems of operating mines.

TABLE 1

UNDERGROUND MINE FIRE CONTROL SEMINARS

BREAKDOWN OF PARTICIPATING ORGANIZATIONS

Mining Companies

Coal

Cape Breton Development Corporation
Cardinal River Coals
Petro-Canada Resources
Smoky River Coal Limited
Westar Mining Ltd.

Non-Coal

Brunswick Mining and Smelting
Canadian Salt Company
Cominco Ltd.
Denison Mines
Echo Bay Mines
Falconbridge
Giant Yellowknife Mines
Inco
Newfoundland Zinc Mines
Westmin Resources

Universities/Research Organizations

Coal Mining Research Centre
Technical University of Nova Scotia
University of Cape Breton

Consultants

Charbonnage de France International
Monenco Consultants Limited
Norwest Resource Consultants Ltd.

.....Cont'd

TABLE 1 Cont'd

UNDERGROUND MINE FIRE CONTROL SEMINARS

BREAKDOWN OF PARTICIPATING ORGANIZATIONS

Government/Industry Associations

Energy, Mines and Petroleum Resources - B.C.	
Energy Mines and Resources, Canada - CANMET	- Sydney, N.S.
	- Calgary, Alta.
	- Ottawa, Ont.
Energy Resources Conservation Board	- Alberta
Indian and Northern Affairs	
Labour Canada	
Mines Accident Prevention Association	- Ontario
Ministry of Labour	- Ontario
Mining Association of British Columbia	
Nova Scotia Department of Mines	
Occupational Health and Safety	- Alberta
Saskatchewan Labour	

Suppliers

Air Products
Canadian Liquid-Air
M.S.A. Canada
Nowsco Well Service Ltd.
Safety Supply Canada
Union Carbide Canada
Union Carbide-Linde

AMCL

One Day Seminar

UNDERGROUND MINE FIRE CONTROL

1984

September 17 - **Sydney, N.S.**
September 19 - **Sudbury, Ont.**
September 24 - **Vancouver, B.C.**
September 25 - **Calgary, Alta.**

Sponsored by
CANMET
Presented by
Associated Mining Consultants Ltd.

UNDERGROUND MINE FIRE

Background

The seminars will review methods and procedures available to control underground mine fires in coal, metal and non-metal mines. The seminars arise from a detailed study, recently completed for CANMET by Associated Mining Consultants Ltd. concerning mine fire control using inert gases. The results of this study will be summarized in one of the sessions. Other sessions will provide a comprehensive review of fire control technology and fire combat experience.

Key Speakers

The seminars will be conducted by internationally recognized experts in underground mine fire control and mine rescue from Canada, France, Germany and UK. Principal speakers will include:

GORDON JOLLIFFE

Manager, NCB District Mine Rescue Service, UK.

FRANJO KOCK

Chief, Mine Rescue Service, SKBV West Germany.

JACQUES LUX

Technical Manager, Charbonnages de France.

JOHN BACHARACH

President, John P.L. Bacharach and Associates Limited.

PROGRAM OUTLINE

Participants

The seminars are designed for corporate and operating management in coal, metal and non-metal mining, safety specialists, rescue personnel and mining inspectors.

Principles and Practices of Mine Fire Control

Methods and procedures available for fire control including a review of the combustion process, detection, hazard identification, fire status monitoring and firefighting operations.

Fire Combat Experience

How fires have been combatted in underground mines using techniques including direct attack, flooding, sealing off and inerting. Actual incidents will be used to illustrate successful approaches.

Areas addressed will include crisis management, ventilation during fire incidents and rescue training and operations.

Sessions will include:

- Fire combat experience in French underground mines
- Operations of the German underground rescue/firefighting services
- Fire control in Canadian mines by inerting.

Emphasis will be placed on practical considerations vital to reduction of fire hazards and effective control of underground mine fires.

CONTROL

Format

The seminars will comprise technical presentations, discussions and case studies. They will provide for interaction between speakers and participants and will encourage the exchange of experience amongst people who have participated in a wide range of underground firefighting situations.

Schedule

Seminar A - Sydney, N.S.
Monday, September 17, 1984.
CBDC Human Resource Centre.

Seminar B - Sudbury, Ont.
Wednesday, September 19, 1984.
Northbury Hotel
50 Brady Street

Seminar C - Vancouver, B.C.
Monday, September 24, 1984.
Holiday Inn - Harbourside
1133 West Hastings Street

Seminar D - Calgary, Alta.
Tuesday, September 25, 1984.
Holiday Inn
8th Avenue and 6th Street, SW

Time: 8:30 a.m. - 4:30 p.m.

Fee

The fee for each seminar is $100.00 and includes admission, handbook and coffee.

The organizers reserve the right to alter the published program details.

Registration Form

Fee in full must accompany registration
Remit by cheque or money order for
$100.00 to:

Associated Mining Consultants Ltd.
Attn: Maxine Swann
6th Floor, 926 - 5 Avenue SW
CALGARY, Alberta, Canada
T2P 0N7 Tel: (403) 264-9496

I will attend:

- ☐ Seminar A - September 17, Sydney, N.S.
- ☐ Seminar B - September 19, Sudbury, Ont.
- ☐ Seminar C - September 24, Vancouver, B.C.
- ☐ Seminar D - September 25, Calgary, Alta.

NAME _____ PHONE _____

HOME ADDRESS _____ POSTAL CODE _____

COMPANY/ORGANIZATION _____

JOB TITLE _____ BUS. PHONE _____

BUS. ADDRESS _____

_____ POSTAL CODE _____

About the Speakers

John Bacharach, is a mining engineer with 20 years experience in the underground mining industry. He has been in engineering operations and international consultancy. He will act as Seminar Chairman.

Gordon Jolliffe is a mining engineer and Manager of the UK National Coal Board's Yorkshire District Rescue Service. He has 30 years industry experience including mine firefighting, ventilation engineering and civil emergencies. He has participated in the combat of more than 200 fire incidents and his responsibilities include rescue organization and incident control for 70 underground mines.

Franjo Kock is a mining engineer with more than 30 years experience in the underground mining industry. He is Chief of the Mine Rescue Centre, Essen, West Germany, and is responsible for the management and standards of a service employing 3,000 rescuemen. Teams in his area have attended more than 800 emergencies in the past 20 years.

Jacques Lux is a mining engineer with extensive experience in the underground mining industry. As Technical Manager, Charbonnages de France, his responsibilities include fire control procedures throughout the French mining industry where many innovative approaches have been developed.

Other Speakers with extensive experience in fire control and rescue operations will be contributing to the seminars.

Registration

To register, please complete the attached registration form and mail, together with fee of $100.00 to:

Associated Mining Consultants Ltd.
Attn: Maxine Swann
6th Floor, 926 - 5 Avenue SW
CALGARY, Alberta, Canada
T2P 0N7
Tel: (403) 264-9496

Cancellations

Must be in writing and must reach AMCL by September 5, 1984, to result in a full refund less $20.00 cancellation fee. If cancellations are not received by September 5, 1984, registrants are liable for the full fee.

Seminar Sponsor

CANMET - under the START program

Seminar Organizer

Associated Mining Consultants Ltd.
Calgary, Alberta, Canada.

A Canadian Mining consultancy offering services that include assistance with mine ventilation engineering, fire control and mine rescue.

FIGURE 1

UNDERGROUND MINE FIRE CONTROL SEMINARS

ENGLISH BROCHURE

Séminaire d'un jour

CONTRÔLE DES FEUX DANS LES MINES SOUTERRAINES

1984

17 septembre	-	**Sydney, N.E.**
19 septembre	-	**Sudbury, Ont.**
24 septembre	-	**Vancouver, C.B.**
25 septembre	-	**Calgary, Alta.**

Commandité par

CANMET

Présenté par

Associated Mining Consultants Ltd.

CONTRÔLE DES FEUX DANS LES MINES

Arrière-plan

Les séminaires passeront en revue les méthodes et les procédés disponibles pour maîtriser les feux dans les mines souterraines de charbon, et d'autres minerais. Les séminaires jaillissent d'une étude détaillée, complétée récemment pour CANMET par Associated Mining Consultants Ltd. concernant le contrôle des feux de mines au moyen de gas inertes. Les résultats de cettètude seront résumés à l'une des sessions. D'autres sessions couvriront d'une manière extensive la technologie du contrôle des feux aussi bien que l'expérience concrète de la maîtrise des incendies.

Principaux conférenciers

Les séminaires seront conduits par des experts d'un renommée internationale en ce qui concerne le contrôle des feux et les opérations de sauvetage dans les mines souterraines du Canada, de France, d'Allemagne et de Grande-Bretagne. Les principaux conférenciers seront:

Gordon Joliffe

Gérant, NCB District Mine Rescue Service, UK.

Franjo Kock

Chef, Mine Rescue Service, SKBV West Germany.

Jacques Lux

Gérant technique, Charbonnages de France.

John Bacharach

Président, John P.L. Bacharach and Associates Limited.

PROGRAMME

Participants

Les séminaires sont préparés à l'intention des directeurs et des gérants d'opération de mines de charbon, de métaux et d'autres minerais. Ils sont aussi à l'intention des spécialistes qui travaillent à la prévention des accidents, du personnel de sauvetage et des inspecteurs de mines.

Principles et pratiques du contrôle des incendies dans les mines

Méthodes et procédés disponsibles pour maîtriser les feux de mines y compris une revue du procédé de combustion, de détection, d'identification des hasards, de surveillance des feux en cours et des opérations du combat des feux.

Manière de combattre les feux

Techniques déjà utilisées pour combattre les feux dans les mines souterraines y compris l'attaque directe, l'arrosage, la méthode d'étanchéite et l'inertion. Des incidents réels décriront les meilleures manières d'aborder ce problème.

On abordera aussi les problèmes d'administration, la ventilation durant un incendie et l'entraînement du personnel de secours.

Les sessions comprendront:

- Manières de combattre les feux dans les mines souterraines françaises
- Opérations des services de secours et de pompiers dans les mines souterraines allemandes
- Contrôle des feux dans les mines canadiennes par le procédé d'inertion

On mettra l'emphase sur des considérations pratiques qui sont vitales pour réduire des dangers d'incendie et pour un contrôle efficace des feux dans les mines souterraines.

SOUTERRAINES

Format

Les séminaires se composeront de présentations techniques et de cas-types. Ils fourniront une occasion d'échanges entre les conférenciers et les participants et un moyen de communication réciproque sur des situations concrètes parmi des gens qui ont une expérience variée de combats de feux dans les mines souterraines.

Horaire

Séminaire A - Sydney, N.E.
Lundi, le 17 septembre 1984
CBDC Human Resource Centre.

Séminaire B - Sudbury, Ont.
Mercredi, le 19 septembre 1984
Northbury Hotel
50 Brady Street

Séminaire C - Vancouver, C.B.
Lundi, le 24 septembre 1984
Holiday Inn - Harbourside
1133 West Hastings Street

Séminaire D - Calgary, Alberta
Mardi, le 25 septembre 1984
Holiday Inn
8th Avenue and 6th Street, SW

De 8:30 a.m. à 4:30 p.m.

Prix

Le prix pour chaque séminaire est de $100.00 et cela comprend l'admission, manuel et café.

Les organisateurs se réservent le droit de faire certains changements si nécessaire.

Formule D'Inscription

J'assisterai au:

☐ Séminaire A - 17 septembre, Sydney, N.E.
☐ Séminaire B - 19 septembre, Sudbury, Ont.
☐ Séminaire C - 24 septembre, Vancouver, C.B.
☐ Séminaire D - 25 septembre, Calgary, Alta.

Le paiement au complet des frais de participation doit accompagner la formule d'inscription. Envoyer un chèque ou un mandat de $100.00 payable à l'ordre de:

Associated Mining Consultants Ltd.
Attn: Maxine Swann
6th Floor, 926 - 5 Avenue SW
CALGARY, Alberta, Canada
T2P 0N7 Tel: (403) 264-9496

NOM _____ TELEPHONE _____

ADRESSE _____ CODE POSTAL _____

COMPAGNIE/SOCIÉTÉ _____

RANG ET TITRE DE L'EMPLOI _____ TEL. BUREAU _____

ADRESSE DU LIEU DE TRAVAIL _____

_____ CODE POSTAL _____

Au sujet des conférenciers

John Bacharach est un ingénieur minier qui a 20 ans d'expérience dans l'industrie minière souterraine. Il a travaillé comme ingénieur d'opérations et comme consultant international. Il sera président du séminaire.

Gordon Joliffe est ingénieur minier et directeur du UK National Coal Board's Yorkshire District Rescue Service. Son expérience de 30 ans dans l'industrie comprend combattre les feux de mines, résoudre des problèmes de ventilation et participer à des situations d'urgence variées. Il a combattu plus de 200 incendies. Ses responsabilitiés actuelles comprennent l'organisation des services de secours et de surveillance pour 70 mines souterraines.

Franjo Kock est un ingénieur minier qui a plus de 30 ans d'expérience dans les mines souterraines. Il est chef du Centre de Sauvetage Minier, Essen, Allemagne de l'Ouest. Il est en charge de 3,000 employés. Des équipes de sauvetage sous sa responsabilité ont prêté main forte dans plus de 800 cas d'urgence durant les 20 dernières années.

Jacques Lux est un ingénieur minier qui a une vaste expérience dans les mines souterraines. Comme gérant technique des Charbonnages de France, il est responsable du contrôle des feux de mines dans toute l'industrie minière française où plusieurs nouveaux procédés ont été développé.

D'autres conférenciers possédant une vaste expérience dans le contrôle des feux et les opérations de sauvetage apporteront leur contribution aux séminaires.

Inscription

Pour s'inscrire, s.v.p. compléter la formule ci-jointe et poster avec paiement de $100.00 pour les frais de participation à:

Associated Mining Consultants Ltd.
Attn: Maxine Swann
6th Floor, 926 - 5 Avenue SW
CALGARY, Alberta, Canada
T2P 0N7
Tel: (403) 264-9496

Annulations

Doit être par écrit et doit être reçu par AMCL avant le 5 septembre 1984, si l'on veut une remise au complet moins $20.00 pour frais d'annulation. Si les annulations ne sont pas reçus avant le 5 septembre les inscrits devront payer plein prix.

Commanditaire

CANMET - dans le câdre du programme START

Organisateurs

Associated Mining Consultants Ltd.
Calgary, Alberta, Canada.

Une société canadienne de consultants miniers offrant des services comprenant la ventilation des mines, le contrôle des feux et les opérations de sauvetage.

FIGURE 2

UNDERGROUND MINE FIRE CONTROL SEMINARS

FRENCH BROCHURE

APPENDIX A

Handbook Distributed at Seminars

(Under Separate Cover)

APPENDIX B

List of Participants

UNDERGROUND MINE FIRE CONTROL

LIST OF PARTICIPANTS - SYDNEY, N.S.

NAME:	Tim Aston
JOB TITLE:	Research Scientist
COMPANY/ORGANIZATION:	CANMET
ADDRESS:	210 George Street, Sydney, N.S., B1P 1J3
PHONE:	(902) 564-7676
NAME:	Thomas Baldwin
JOB TITLE:	General Mine Manager
COMPANY/ORGANIZATION:	Cape Breton Development Corporation
ADDRESS:	Prince Mine, Point Aconi, Nova Scotia
PHONE:	(902) 564-3301
NAME:	Joseph Burke
JOB TITLE:	Safety Inspector
COMPANY/ORGANIZATION:	United Mine Workers
ADDRESS:	PO Box 129, Glace Bay, Nova Scotia, B1A 5V2
PHONE:	(902) 849-8692
NAME:	Gary Bonnell
JOB TITLE:	Supervising Chemist
COMPANY/ORGANIZATION:	Cape Breton Coal Research Lab.
ADDRESS:	210 George Street, Sydney, N.S., B1P 1J3
PHONE:	(902) 564-7681
NAME:	J.H. Hall Chamberlin
JOB TITLE:	Senior Mining Engineer
COMPANY/ORGANIZATION:	Associated Mining Consultants Ltd.
ADDRESS:	6th Fl., 926 - 5 Avenue SW, Calgary, Alberta, T2P 0N7
PHONE:	(403) 264-9496
NAME:	Robert Cooper
JOB TITLE:	Director, Mining Operations
COMPANY/ORGANIZATION:	Cape Breton Development Corporation
ADDRESS:	PO Box 2500, Sydney, Nova Scotia, B1P 6K9
PHONE:	(902) 564-2804

LIST OF PARTICIPANTS Cont'd.

NAME:	Gary Corbett
JOB TITLE:	Laboratory Tech.
COMPANY/ORGANIZATION:	Energy, Mines & Resources
ADDRESS:	436 George Street, Sydney, Nova Scotia
PHONE:	(902) 564-6593
NAME:	Edward Durdle
JOB TITLE:	Manager - Lingan Mine
COMPANY/ORGANIZATION:	Cape Breton Development Corporation
ADDRESS:	PO Box 2500, Sydney, Nova Scotia, B1P 6K9
PHONE:	(902) 564-3105
NAME:	Walter Fell
JOB TITLE:	Chief Inspector of Mines
COMPANY/ORGANIZATION:	NS Dept. of Mines and Energy
ADDRESS:	PO Box 1087, Halifax, Nova Scotia, B3J 2X1
PHONE:	(902) 424-4049
NAME:	J.J. Fix
JOB TITLE:	General Manager
COMPANY/ORGANIZATION:	CdF International
ADDRESS:	706 Granville Street, Suite 407, Vancouver, British Columbia
PHONE:	(604) 684-5371
NAME:	George Haslett
JOB TITLE:	Project Engineer
COMPANY/ORGANIZATION:	CANMET
ADDRESS:	436 George Street, Sydney, Nova Scotia, B1P 1J3
PHONE:	(902) 564-7674
NAME:	Jagdish Kochhar
JOB TITLE:	Chief Mining Engineer
COMPANY/ORGANIZATION:	Cape Breton Development Corporation
ADDRESS:	PO Box 2500, Sydney, Nova Scotia, B1P 6K9
PHONE:	(902) 564-2900

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LIST OF PARTICIPANTS Cont'd.

NAME:	Dr. Balesh W. Konda
JOB TITLE:	Mine Environment Scientist
COMPANY/ORGANIZATION:	Energy, Mines & Resources
ADDRESS:	436 George Street, Sydney, Nova Scotia
PHONE:	(902) 564-6593
NAME:	Jude Kelly
JOB TITLE:	Electrical/Mechanical Inspector
COMPANY/ORGANIZATION:	Dept. of Mines & Energy
ADDRESS:	PO Box 67, Glace Bay, Cape Breton, B1A 5V1
PHONE:	(902) 849-7500
NAME:	Kris Larsen
JOB TITLE:	Mine Rescue Co-ordinator
COMPANY/ORGANIZATION:	Canadian Salt Co. Ltd.
ADDRESS:	PO Box 160, Pugwash, Nova Scotia, B0K 1L0
PHONE:	(902) 243-2511
NAME:	J. Wayne LeBlanc
JOB TITLE:	General Mine Manager
COMPANY/ORGANIZATION:	Cape Breton Development Corporation
ADDRESS:	PO Box 2500, Sydney, Nova Scotia, B1P 6K9
PHONE:	(902) 564-2719
NAME:	David Little
JOB TITLE:	Chief Safety Inspector
COMPANY/ORGANIZATION:	Cape Breton Development Corporation
ADDRESS:	PO Box 2500, Sydney, Nova Scotia, B1P 6K9
PHONE:	(902) 564-2898
NAME:	Albert McLean
JOB TITLE:	Mine Rescue/First Aid Instructor/Inspector
COMPANY/ORGANIZATION:	NS Dept. of Mines & Energy
ADDRESS:	PO Box 67, Glace Bay, Nova Scotia, B1A 5V1
PHONE:	(902) 849-7500

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LIST OF PARTICIPANTS Cont'd.

NAME:	A. Roy MacLean
JOB TITLE:	Mining Engineer
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UNDERGROUND MINE FIRE CONTROL

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UNDERGROUND MINE FIRE CONTROL

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One Day Seminar

UNDERGROUND MINE FIRE CONTROL

HANDBOOK

1984

September 17 - **Sydney, N.S.**
September 19 - **Sudbury, Ont.**
September 24 - **Vancouver, B.C.**
September 25 - **Calgary, Alta.**

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UNDERGROUND MINE FIRE CONTROL

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UNDERGROUND MINE FIRE CONTROL
EXECUTIVE SUMMARY

The objective of the seminar is to transfer to the Canadian mining industry the results of the recently completed CANMET contract which reviewed the status of underground mine fire control with inerting systems and to provide a forum for discussion and dialogue between underground mine firefighting specialists and the Canadian mining industry.

The seminar is divided into four main sections. In the first, Gordon Jolliffe reviews the principles and practice of mine fire control. In this session the causes and types of mine fires are discussed. The combustion process is analyzed in terms of fire source, fuels, spontaneous combustion and the products and spread of fire. Means of detection of underground fires ranging from human observation to sophisticated environmental monitoring systems are reviewed. Emphasis is placed on the effects of the fire, including explosion risk, flammable gases, heat and the effect of fire on the mine ventilation system.

Firefighting operations are reviewed including direct and indirect means of attack and comments are made on a number of practical aspects. The technique for pressure balancing is described. The session concludes with a review of the precautions that can be taken to minimize the risk of fire from the planning stage through to the control of operations. Personal protection is discussed and the need to prepare contingency plans is stressed.

In the second session, Franjo Kock, Head of the Mine Rescue Centre in Essen, West Germany, reviews the operations of the German mine rescue/firefighting service. He describes the conditions prevailing in the Rhur Coalfield and the organization of the central rescue station and minesite facilities. The widespread use of nitrogen in fire control is described and successful

experience with this technique at a number of German mines is discussed. Techniques for rescue operations are reviewed, including the management of rescue actions, communications during an emergency and mutual assistance between mines and coalfields. The adverse conditions of high humidity and temperature encountered by firefighters are described and advice is given on the organization of an incident to maximize the efficiency of the rescue operation. The importance of thorough training is stressed and the extensive facilities and programs available for rescue training in the German mining industry are reviewed.

In the third paper, Claude Froger of Charbonnage de France describes the principal causes of fires in French mines. The improvement in fire control brought about by the widespread use of nitrogen is illustrated through a number of case studies, including the use of nitrogen as a preventative measure and in the case of controlling a major open fire. The latest developments in individual personnel protection are described and the value of oxygen self-rescuers is illustrated. The interaction between the effects of a fire and a normal ventilation system of a mine are discussed.

In the final paper, John Bacharach reviews the findings of the CANMET inerting study and describes the three principle inerting media - nitrogen, carbon dioxide and products of combustion. The techniques for the application of these firefighting methods are discussed and recommendations made that nitrogen be adopted as the most appropriate method of inerting fires in Canadian coal mines. Reference is made to the inert gas generator which has potential for fire control in non-coal mines and in certain coal mines.

The seminar provides an opportunity for an exchange of views between the speakers and industry representatives. Participants have been provided with a seminar handbook containing a large volume of relevant information.

CONTRÔLE DES FEUX DANS LES MINES SOUTERRAINES

SOMMAIRE

Ce séminaire a pour objectif de transférer à l'industrie minière canadienne les résultats d'une étude complétée récemment pour CANMET concernant le lutte contre les feux dans les mines souterraines par le procédé d'inertisation et de fournir une occasion d'échanges et de dialogues entre des spécialistes du combat des feux dans les mines souterraines et l'industrie minière canadienne.

Le séminaire est divisé en quatre parties. Dans la première partie, Gordon Jolliffe présente les principles et les aspects pratiques de la lutte contre les incendies souterrains. Les causes et les différentes sortes de feux y sont discutées. On y analyse aussi le procédé de combustion en termes de l'origine des feux, des combustibles, des échauffements spontanés, des produits et de l'étendue des feux. Les moyens de détection des feux souterrains allant de la simple observation humaine jusqu'aux systèmes sophistiqés de surveillance de l'environement y sont revisés. On met l'emphase sur les effets des feux y compris les risques d'explosion, les gaz inflammables, l'énergie calorifique et les effets des feux sur le système de ventilation. M. Jolliffe passe en revue les moyens de combattre les feux y compris l'attaque directe et indirecte et fait des commentaires sur une variété d'aspects pratiques. Il décrit également la technique de pression équilibrée. Cette partie se termine par une revue des précautions à prendre afin de minimiser les risques d'incendies du stade initial de planification jusqu'au contrôle des opérations. On y discute la sécurité personnelle et on insiste sur le besoin de préparer des plans d'urgence.

Dans la deuxième partie, Franjo Kock, chef du Centre de Sauvetage Minier, Essen, Allemagne de l'Ouest, passe en revue les opérations des services allemands de secours et de pompiers. Il décrit les conditions dominantes dans les champs de charbon de Ruhr ainsi que l'organisation du poste central de sauvetage et les accomodations des sites miniers. Il décrit aussi l'usage répandu d'utiliser de l'azote dans la lutte contre les feux et il discute les succès que cette technique a recontrés dans un certain nombre de mines allemandes. Les techniques d'opérations de sauvetage sont présentées ici y compris la conduite des interventions de sauvetage, les communictions durant les situations d'urgence et l'assistance mutuelle entre les mines et les champs de charbon. Il parle des conditions défavorables de grande humidité et de haute température auxquelles les pompiers ont à faire face et il donne des conseils sur l'organisation d'une intervention afin que l'opération de sauvetage soit d'une efficacité maximale. Il appuie fortement sur l'importance d'un entraînement complet et il détaille les vastes accomodations ainsi que les programmes disponibles pour l'entraînment de secours dans l'industrie minière allemande.

Dans la troisième partie, Claude Froger, des Charbonnages de France, décrit les principales causes de feux dans les mines francaises. Les progrès dans la lutte contre les feux, dus a l'usage répandu de l'azote, sont illustrés à l'aide de cas-types y compris l'usage de l'azote en tant que mesure préventive aussi bien qu'en tant qu'agent de contrôle dans le cas de feux majeurs. Il parle des derniers progrès dans la protection individuelle personnelle et il illustre une manière valable de se sauver soi-même à l'aide d'oxygène. Il aborde aussi l'interaction entre les effets d'un feu et le système normal de ventilation d'une mine.

Dans un dernier temps, John Bacharach passe en revue les conclusions de l'étude CANMET sur l'inertisation et il décrit les trois principaux procédés d'inertisation - l'azote, le gaz carbonique et les produits combustibles grazeux. Les techniques nécessaires à l'application de ces méthodes de contrôle des feux sont discutées et on y recommande que la technique de

l'inertisation à l'azote soit adoptée comme la méthode la mieux appropriée aux mines canadiannes. On fera également mention d'un générateur de gaz inerte qui a un certain potentiel pour contrôler les feux dans les mines en général et dans certaines mines de charbon en particulier.

Le séminaire se veut une occasion d'échange de points de vue entre les conférenciers et les représentants de l'industrie. On a distribué aux participants un manuel contenant une grande quantité d'informations pertinentes.

AR-72.2

UNDERGROUND MINE FIRE CONTROL

PROGRAM

8:30	- 8:45	Welcome/Introduction - Bruce Stewart
8:45	- 10:15	Principles and Practice of Mine Fire Combat Gordon Jolliffe
10:15	- 10:30	Coffee
10:30	- 12:00	Operations of the German Mine Rescue/Fire Fighting Service, Franjo Kock
12:00	- 1:15	Lunch
1:15	- 2:45	Fire Combat Experience in French Underground Mines Claude Froger
2:45	- 3:30	Fire Control with Inerting for Canadian Underground Mines John Bacharach
3:30	- 3:45	Coffee
3:45	- 4:30	Discussion

AR-72.2

UNDERGROUND MINE FIRE CONTROL

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AR-72.2

UNDERGROUND MINE FIRE CONTROL

SECTION 1

INTRODUCTION

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UNDERGROUND MINE FIRE CONTROL

INTRODUCTION

This series of one-day seminars is intended to accomplish two objectives:

- To transfer to the Canadian mining industry the results of a recently completed CANMET contract study that reviewed the current status of underground mine fire control with inerting systems.
- To provide a forum for discussion and dialogue between underground mine fire fighting specialists and the Canadian mining industry.

While all of us strive to reduce the likelihood of underground fires, we must recognize the potential risks and consequences of such events and be suitably prepared.

CANMET takes great pleasure in sponsoring this series of seminars. We encourage each of you to participate fully in today's program and trust that today's discussions will help you respond effectively should you ever be called upon to deal with an underground mine fire situation.

CONTRÔLE DES FEUX DANS LES MINES SOUTERRAINES

INTRODUCTION

Ces séminaires d'un jour se proposent deux objectifs:

- Transférer à l'industrie miniére canadienne les reésultats d'une étude complétée récemment pour CANMET concernant la situation actuelle du contrôle des feux dans les mines souterraines par le procédé d'inertisation.
- Fournir une occasion d'échanges et de dialogues entre des spécialistes du combat des feux dans les mines souterraines et l'industrie minière canadienne.

Bien que chacun de nous travaille à réduire les risques d'incendies dans les mines souterraines nous sous devons de reconnaître les dangers et les conséquences de telles éventualités pour lesquelles nous devons être convenablement préparés.

CANMET est heureux de promouvoir ces séminaires. Nous encourageons tous et chacun de vous à participer entièrement au programme d'aujourd'hui et nous espérons que les discussions vous aideront à maîtriser efficacement un feu de mines si jamais une telle situation se présente.

AR-72.2

UNDERGROUND MINE FIRE CONTROL

SECTION 2

PRINCIPLES AND PRACTICE OF MINE FIRE CONTROL

by

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COMBATTING UNDERGROUND MINE FIRES
TWO DAY WORKSHOP SEPTEMBER 20/21, 1984

SECTION 2 - PRINCIPLES AND PRACTICE OF MINE FIRE CONTROL

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SECTION 2 - PRINCIPLES AND PRACTICE OF MINE FIRE CONTROL

2.1 GENERAL

Many thousands of mine workers have lost their lives during fires in coal mines. In addition, fires have frequently caused the abandonment of many mines or the sterilization of large reserves of coal. In one particularly serious disaster a fire in a coal mine in Manchuria during the Second World War resulted in the death of 1 500 miners. Thus the prevention and control of underground mine fires has both safety and economic implications.

2.2 CAUSES OF MINE FIRES

The main causes of underground mine fires include:

- Conveyors.
- Frictional ignition.
- Spontaneous combustion.
- Electrical equipment.
- Inadequate legal standards of enforcement that allow:
  - smoking
  - non-flameproof materials
  - unsuitable explosives
  - electrical equipment such as heaters and kettles.

2.3 TYPES OF FIRE

2.3.1 Small Fires

A small fire is confined to a localized and exposed surface. For example, a fluid coupling on a trunk conveyor may overheat and set fire to oils and fluids, pumps may run dry and stators or motors become ignited. Other examples include waste paper catching fire, and fires in small piles of coal or dust under conveyor belts, near loading points, or resulting from small falls.

Such fires should be tackled immediately on discovery by personnel at hand, using whatever materials are available. It must be recognised that a small fire is always potentially a large one.

2.3.2 Large Fires

A large fire is one which completely fills the roadway with flame, burning materials or fire gases and the floor, sides and roof of the roadway may be alight. Such a fire has the most serious implications on the safety of the mine because noxious fumes may spread through a considerable length of roadways, and the risk of explosions or 'flash overs' of fire gases is present. Thermal effects can influence normal mine ventilation, locally and throughout the mine.

2.3.3 Deep-seated Fires

Such fires (heatings) are located remotely from the roadways. Physical signs of fire such as flame and fire noise are absent, though other signs of fire may be present to some degree, such as smell, smoke, heat, condensation and the emmission of the products of combustion. Some of the signs such as heat and

condensation may be absent in some cases, but others such as smell and the products of combustion, can be picked up in the mine ventilation, either from an identifiable spot - a seal or stopping - or, more usually, progressively along a section of roadway.

The location of a heating may be a few centimetres into the sides, roof or floor of the roadway or up to several kilometres from the mine workings themselves. There are many instances of heatings occurring in old workings or outcrops passing products of combustion considerable distances underground through old gob, broken ground, or old mine workings, to emerge in the active workings of a mine.

Most heatings consist of oxidization of strata (not necessarily of high carbonaceous content) causing a rise in temperature that drives off volatiles and partial combustion products. The rate at which the carbonaceous material is consumed is usually low. For example a heating producing a pollution of 100 ppm (0.01%) CO in a ventilation current of 9.4 m^3/sec consumes about 4.5 kg of fuel per hour.

2.3.4 Hanging Flames

This term describes the situation where methane has been ignited and flame has travelled into breaks in the strata, or gob areas, and continues to burn in places remote from the workings, or the original ignition point. Such a flame can burn indefinitely as long as methane and oxygen are available. The heat produced can weaken the strata and exposed carbonaceous materials can be set on fire. If the flame reaches any pockets of methane/air mixture, explosions can result. A hanging flame is unstable and can travel backwards and forwards along strata breaks. It is virtually

impossible to extinguish such flames by direct means and the most effective treatment is by sealing off or inerting.

2.3.5 Gas Jet Fires

Gas flares are common in the oil industry when a well catches fire, but they also occur in mines when gas under pressure from a borehole drilled for shotfiring, methane drainage, or from strata breaks, is ignited. Should gas become ignited by shotfiring or open fire in a roadway where methane drainage is practiced, then a continuously burning gas flare can result. It is often possible to extinguish flares by direct means such as stopping the flow of gas by closing the stand pipe valve on a methane borehole, or by the use of dry powder extinguishers.

2.3.6 Concealed Fires

These are cases of 'open' fires which occur behind structures or lining of roadways and are not immediately detected. It is virtually impossible to extinguish such flames by direct means due to the problem of access.

2.3.7 Surface Fires

Smoke and products of combustion from fires on the surface can be drawn into the mine by the ventilation current. Traces of carbon monoxide may register on underground air sampling or monitoring systems. Building, grass or forest fires near a mine have also been known to pollute the underground mine ventilation system.

2.4 COMBUSTION PROCESS

2.4.1 Fire

Fire is essentially the reaction of substances with oxygen at a sufficiently high rate to produce increased temperatures. Many substances react with oxygen in the atmosphere, but at a rate insufficient to cause increase in temperature, for example, the rusting of iron. In the fire situation, the substance is called 'a fuel'.

For a fire to occur, the necessary elements are fuel, heat and oxygen. If any one is missing, then no fire can result. If a fire is burning and one of the factors is removed, then the fire will go out. The basis of fire-fighting is, therefore, to remove one or more contributing factors from the situation. The fire may be starved of air and hence oxygen, the fuel source may be removed or the burning materials cooled.

2.4.2 Fuels

Fuels encountered in underground coal mines can be divided into two categories, namely:

Indigenous (naturally present)

- methane
- coal
- oil (occasionally)

Imported materials (taken underground)

- timber
- plastic materials
- flammable liquids and greases
- others, eg paper

Imported materials such as timber supports, are usually the medium through which a small fire develops into a severe one. This problem can be designed out, to some degree, by limiting their use particularly at vulnerable places such as conveyor transfer points. All combustible materials taken underground should be fire resistant. For example, fire resistant fluids should be used for hydraulic power systems.

The indigenous fuel supply can be controlled to some extent. Methane hazards can be reduced by good standards of ventilation supplemented by methane drainage. Coal dust should be prevented from accumulating near any potential source of fire. The fire hazard of coal itself can be reduced by the construction of fire-proof linings at transfer and loading points.

2.4.3 Spontaneous Combustion

Certain seams are known to be prone to spontaneous combustion, whilst others rarely experience it. The most common cause is the leakage of air through carbonaceous strata. Good ventilation engineering and practices are the best prevention. Workings should be well ventilated with pressures across old workings or gobs etc. kept as low as possible. The siting and construction of air crossings and ventilation doors are important, and airways should be as free of obstruction as possible.

The second most common cause is the existence of crushed coal and other combustible materials in vulnerable places. Insufficient planning can give crushed coal conditions when small pillars of coal are left or when roadways meet at acute angles. Badly designed air crossings and other structures also cause coal to be crushed, allowing air to enter. Some heatings can be prevented by moving timber from waste areas and avoiding building loose coal

into packs. Other causes include poor ventilation due to delay in sealing off old districts.

The presence of moisture in the coal or in the ventilation, and certain chemical substances such as pyrites appear to act as catalysts to induce heatings.

The oxidation of the coaly substance generates heat, and if this heat is not removed the oxidation process escalates and the temperature rises. This is the case where crushed coal is exposed to the seepage of low quantities of air.

The earliest sign of a heating is a characteristic oily smell in the ventilation. This is followed by a phenomena known as 'sweating' where condensation of water vapour is seen on the supports and linings of the adjacent airway. More physical signs develop as the heating progresses including an increase in temperature on the roadside near the heating, warm vapour emission points followed by wisps of vapour and, later, smoke issuing from the roadside. Finally, the temperature rises to the point of ignition and open fire breaks out in the affected area. These symptoms are summarized in Figure 2-1.

2.4.4 Products of Combustion

The gaseous products of a fire underground are:

- Smoke

  Smoke can vary from a light haze to a black mass through which it is impossible to see. Even though such smoke may be diluted as it travels outbye, it is possible for it to be clearly visible in all the airways up to the discharge from

the main fan. Because of the associated thermal effect, it is common for smoke to form layers near the fire with dense smoke near the roof and fresh air near the floor of the airways. The smoke is likely to move backwards against the air current at the roof near the fire. Work in smoke usually involves the use of trained rescue teams equipped with smoke goggles and life lines.

- **Water Vapour**

Water is formed during combustion. The inherent moisture in the strata is driven off by the heat of combustion, and water from fire fighting materials evaporates. High humidities are, therefore, usually experienced downwind of the fire. The atmosphere in static air in sealed off areas becomes fully saturated. This factor has a considerable influence on fire fighting operations and or rescue work following a fire. To a smaller extent, there can be condensation problems with equipment and materials.

- **Carbon Dioxide**

Carbon dioxide is produced in large quantities by all forms of combustion. Readings of up to 5% are observed in the atmosphere downstream of the fire and may be in excess of 10% in fire sealed areas. At concentrations above 5%, carbon dioxide has the effect of increasing the breathing rate, and can be lethal at 10% and over.

- **Carbon Monoxide**

Carbon monoxide, an inflammable gas, is formed by the incomplete combustion of carbon and oxygen. If the availa-

bility of oxygen is restricted as in the case of spontaneous combustion, the proportion of carbon monoxide increases.

Carbon monoxide is normally present in mine ventilation to the extent of several parts per million, and this 'norm' should be known for each mine or section. A significant rise above this 'norm' is one of the earliest signs of a fire or heating and each level of increase requires an appropriate response. A consistent reading above 50 ppm confirms the presence of active combustion and requires remedial action. For concentrations above 100 ppm standby cover by men with breathing apparatus is indicated and at concentrations over 200 ppm continuous work should be undertaken only by rescue teams with breathing apparatus.

Carbon monoxide is a highly toxic gas, and headaches and dizziness are experienced at concentrations above 150 ppm. Concentrations of 0.5% and over can cause unconsciousness within seconds and are fatal in a very short time. Details of the physiological effects of carbon monoxide are given in Figure 2-2.

- **Hydrogen**

Hydrogen is produced by fires when water comes into direct contact with hot carbonaceous material. It is produced when a jet of water hits burning coal, when grout is injected into heated strata, or when pools of water submerge burning materials. Usually the concentrations of hydrogen produced in the ventilation can be measured in parts per million, but in some circumstances, much higher quantities can be produced ranging up to 3% of the atmosphere.

Hydrogen is flammable at concentrations of 2% in air and becomes violently explosive at slightly higher concentrations.

- **Other Gases**

  The combustion reaction produces, in small quantities, a range of other organic gases including ethane, propane, ethelene and aromatics such as benzene and toluene. Should other materials particularly plastics, be involved in the fire, other toxic gases such as ammonia, oxides of nitrogen, hydrogen cyanides, phosgene, and hydrogen chloride can be produced.

The gas mixture produced by fires are very complex and requires both good facilities for analysis and an understanding of the hazards which are present. Many of the gases are flammable. In addition, methane may be present in the mine ventilation from other sources.

As an example the composition of the atmosphere at the time of completing a stopping during a spontaneous combustion incident was:

methane	0.95%
oxygen	10.7 %
carbon dioxide	8.5 %
carbon monoxide	1.41%
hydrogen	1.35%

This mixture approaches the explosive limit, and is lethal to personnel.

2.4.5 Spread of Fire

If not tackled promptly, a small open fire can spread downwind using whatever fuel source available. The heat developed will be intense enough to jump over non-inflammable sections of roadway. The rate of advance of the fire is related to the velocity of the ventilation, and the gradient of the roadway. Fire spreads typically at the rate of 30 m/h.

Some recent examples of the development of fires in mines include:

- An inspection at 03:00 hrs of the return roadway of a longwall face during salvage showed no fire. At 05:30 hrs, 5 m of the roadway were on fire and by 07:30 hrs 20 m were ablaze.

- A fire at an air crossing travelled inbye along the intake for an unknown distance producing intolerable smoke and heat for about 1000 m downwind.

- A small fire at the bottom of a return drift spread to envelope most of the drift and finally killed 16 rescue men when the products of combustion exploded during sealing off operations.

- A belt fire in a return drift about 1200 m from the shaft bottom, spread and produced temperatures which resulted in the death of 6 rescue men from the heat developed, as they were being lowered down a shaft.

- A fire in a control cabin near a shaft bottom, spread behind the roadway lining. Rescue teams took less than an hour to

extinguish the cabin fire, but it took a further six hours to put out the fire behind the roadway covering. The fire had spread about 60 m.

2.5 DETECTION OF FIRE

2.5.1 Human

Human beings are very effective fire detectors, using their facilities of sensing and behaviour in the following ways:

- **Smell**

The human nose is a most sensitive detector, in some cases being more sensitive than the best scientific apparatus. It can detect some gases in concentrations as low as one part in ten million. Experienced mining people can detect an unusual smell, and suspect a fire, immediately upon entering a return shaft or airway, sometimes kilometres from the fire. The exact location of a heating, or an emission point of fire gases can be detected by 'sniffing'. The suspected area should be approached from the intake side since the sense of smell is deadened by prolonged exposure and an approach from the return side is less reliable. The ability to interpret smell into incident or fire types is gained only by experience.

- **Sight**

Smoke and haze can be reliably identified by sight, and shaft important distinction between the two recognized. Glowing or flaming objects are readily sighted in dark surroundings.

- **Touch**

  In the early stages of fire or heating, there are points in the roadway which require attention and can readily be detected by touching the roof, sides or floor. The sense of detecting radiant heat can be developed as an aid to detecting remote hot spots.

- **Hearing**

  Hearing is important when smoke and heat prevents the other senses being used and the crackling of the fire, the spitting of the strata and the sound of roof falls (large or small) are valuable aids to safety and effectiveness.

The most valuable means of detecting a fire is a conscientious routine inspection procedure required by the safety rules of the mine. Far more fires have been detected by this means than by more sophisticated systems described later.

2.5.2 Canaries

Canaries, small birds or small animals have traditionally been used to safeguard men working in a CO hazard. The advantages of using canaries is that the indication is direct, continuous and positive. The disadvantage is that the bird may become acclimatized to CO and fail to respond to low percentages.

A bird will become distressed and fall off his perch after about 16 minutes at a concentration of 1,250 ppm whereas a man would not be in danger of collapse until after about 30 minutes at the same concentration. On the other hand, birds will not show any signs of distress until about the 500 ppm level is reached, whereas a man

will start to experience headaches and dizziness at about 150 ppm.

2.5.3 Smoke Detectors

These detectors react to smoke particles rather than the presence of gaseous products of combustion. They are suspended from the roof at strategic points and are arranged to provide a local or remote alarm. Although designs have been improved in recent years, they have been found to be unreliable in use, responding to certain types of dust in the atmosphere and to shotfiring and diesel fumes.

2.5.4 Infra Red Detectors

The device is available in the form of an infra red camera which displays an image derived from the infra red light source on a small television screen. For rescue purposes they can be used to detect living casualties up to 40 m through dense smoke, but in the fire detection role they are used to examine the lining of roadways for any hot spots resulting from a heating. They can detect hot bearings and overheating electrical equipment. These devices have been used successfully but are expensive and require skill in operation. A simpler instrument is the infra red thermometer which will indicate the temperature of a remote object.

2.5.5 Air Sample Analysers

These detect fire and heatings from the presence of combustion gases, principally carbon monoxide. They can be either portable or fixed systems.

Portable CO meters give instantaneous readings and have either a low range (0 to 500 ppm) or a high range (0 to 2%). There are electronic instruments which give a digital readout, but can include other gases in addition to carbon monoxide.

Certain instruments have been designed to detect fire by responding to the combined product of combustion gases, including CO. These include instruments which give a more quantitative assessment of the intensity of the fire. In the course of development are multi-gas analysers which give the values of oxygen, CO and methane.

The electronic instruments can give remote alarm and indication, and can be incorporated into a comprehensive monitoring system. Tube bundle systems that draw samples to the surface from the mine through plastic tubes for analysis and indication, are installed in many mines and give a high standard of control. They suffer from the disadvantage of the time delay taken (up to two hours in some cases) for the sample to travel along the pipe to the analyser on the surface.

Monitoring systems require careful design to avoid false alarms caused, for example, by picking up shotfiring fumes. Their effectiveness depends upon having trained operators available to interpret the results obtained.

2.5.6 Carbon Monoxide / Oxygen Deficiency Ratio

The carbon monoxide/oxygen deficiency ratio is often used as an indication of the presence and intensity of fire, because it is independent of changes in ventilation. The ratio expressed as a fraction has the actual concentration of CO in the ventilating air as the numerator and the deficiency of oxygen compared with

fresh air as the denominator, the whole being multiplied by 100 to give a convenient figure. Changes in the ventilation alters both the numerator and the denominator, hence the ratio is independent of ventilation changes, provided that the incoming air itself has no oxygen deficiency.

The interpretations of the $CO:O_2$ ratio into stages of a fire is shown in Figure 2-1, but since a plot of the ratio against time almost invariably follows the same pattern as the plot of the CO analysis, the additional information obtained from the $CO:O_2$ ratio is limited. Some authorities, however, believe it has value for appraising samples taken from methane boreholes or from deep wastes where the analysis is not representative of normal air.

2.6 EFFECTS OF FIRE

2.6.1 Fire Products

A fire underground can have a dramatic effect on all aspects of a mining operation. It poses a threat to the safety of men, leads to loss of production, restricts of movement and disrupts routine and often incurs a considerable financial expenditure.

The effects of mine fires are summarized in Figure 2-3.

- **Flame**

  Fire in a mine is a frightening experience and a section of roadway on fire throughout its perimeter is reminiscent of looking into a wood stove.

- **Smoke**

The density of smoke depends on the intensity of the fire and the materials involved. For example, a fire of polyurethane foam or mineral oil generates very black smoke. Wood, on the other hand, usually produces a greyish smoke containing organic vapours which cause the eyes to run and the throat to become dry, usually well before there is any danger from toxicity.

- **Noxious Gases**

The production of carbon dioxide, carbon monoxide and the chemical gases constitute one of the major safety hazards in a fire incident. It is for this reason that all personnel should be kept out of any part of the mine downwind of the incident. Access downwind should only be attempted by men wearing breathing apparatus. The atmosphere may still be lethal even though other signs of fire such as heat and smoke have been diluted or have dispersed. This hazard can exist in or at the top of an upcast shaft, in the fan drift and even on the surface of the mine downwind of the upcast shaft. Rescue teams should examine for toxicity; 'Danger Zone' notices should be posted at all doors or points of access into the return airway. Rigid instructions should be issued to all involved as to which parts of the mine are safe or unsafe. At one incident first reports said that the upcast shaft was polluted with 30 ppm of CO and therefore safe for men to travel. However, the first rescue team to descend took the precaution of taking a CO reading which registered 1700 ppm. Any person riding the shaft without breathing apparatus would have arrived at the pit bottom unconscious.

2.6.2 Explosion Risk

Open flame or incandescent materials constitute continuous sources of ignition. If inflammable gases, such as methane or the combustible products of combustion, are present in the right proportions, ignition will take place. If gas percentages are within certain levels, the ignition will be violent and can propagate into a coal dust explosion. Ventilation circuits may be damaged by the first explosion, and it is possible that there can be a succession of explosions. These are particularly dangerous to the rescuers dealing with the original incident.

To ascertain the explosion hazard at a fire, it is essential to have a reliable reading of the amounts of methane and oxygen present.

The properties of the atmosphere are most conveniently appraised by reference to the Coward diagram, shown in Figure 2-4. The diagram presumes that the atmosphere is composed exclusively of air and methane and that there may be some degree of oxygen deficiency present. The diagram is used for control purposes by plotting each successive gas analysis on a copy of the diagram and joining these points with a line. A trend will become apparent. If the line is slowly extending in Section C of the diagram it will eventually enter the explosive area. The rate at which the line is extending will also provide a forecast of when it is likely to happen. If the line is extending in part D then there is no danger of an explosion taking place.

If the atmosphere is diluted with fresh air through increased ventilation or reduced flammable gases then the trend of the plot line would be reversed towards the fresh air point, ie 21% of oxygen and nil % of methane. If this occurs when the plots are in Area A, C or D of the diagram, then the explosion hazard is being

progressively removed. If, on the other hand, the sample analysis falls in Area B, then dilution with air can cause the atmosphere to move through the explosive range, a phenomenum which occasionally occurs in a mine fire situation, often with disasterous results.

If oxygen was progressively removed, then the line plot would move vertically downwards to the extinctive areas. This is what occurs when an inert gas is introduced to the fire situation.

2.6.3 Flammable Gases

In addition to methane, fire gases always contain other flammable gases, principally carbon monoxide and hydrogen which have different flammability characteristics to methane. For instance, hydrogen is explosive at concentrations between 2% and 70% when mixed with air. It is therefore necessary to consider the total amounts of flammable gases present when determining the explosion risk. The explosive limits of gas mixtures differ from those of individual gases.

Minicomputer programs are available which estimate the explosibility hazard and can be taken to the site of a major incident. When the computer system is not available, the Hughes and Raybold graphical method can be employed (Appendix B)

2.6.4 Fuel and Oxygen Rich Fires

A fire is said to be oxygen rich when the oxygen supply is more than adequate to react fully with the fuel decomposed by the heat from the fire. Conversely, a fire is fuel rich when the oxygen supply is insufficient to react fully with the available fuel. It has been found that the rate of spread of an oxygen rich fire is directly proportional to the velocity of the ventilation. The

spread of the fire becomes very rapid and unaffected by ventilation speed in the fuel rich condition, and the admission of extra oxygen in these conditions can lead to explosions and 'flash overs'. Reduction in ventilation can cause a change from the oxygen rich to the fuel rich condition.

Referring to the Coward diagram (Figure 2-4), the area C represents oxygen rich condition and the area B represents the fuel rich condition. Any uncontrolled transition between one and the other produces a condition in area A, the explosive triangle.

2.6.5 Heat

The temperature of the burning materials in the mine depends largely on the quantity of the ventilation.

Air temperatures have been recorded at over 1000°C immediately downwind of a fire and at 200°C, 100 m downstream. Strata downwind will act as a heat sink but because of poor thermal conductivity will retain this heat. Higher strata temperatures in turn reduce heat transfer rates and extends the downwind elevated temperature zone. The high temperatures will destroy most materials, with even heavy steel structures distorting or disintegrating. Exposed strata will be cracked by the heat and will become unstable. For this reason, it is generally impossible to fight a fire from the downwind side.

2.6.6 Effects on Ventilation

A fire can affect the ventilation systems throughout the mine in two ways:

a. **Constriction** - this effect is brought about by a substantial increase in the volume of the ventilation as it passes through the fire. It expands due to the heat and the addition of fire gases. This increased volume in the roadway immediately downwind of the fire requires extra ventilation pressure to maintain the flow and consequently, the flow is reduced as it would be if resistance to the system was introduced. Since this is caused by the considerable increase in temperature, through the fire area, and since the temperature decreases some distance downwind of the fire, the constriction effect is therefore mainly generated in the vicinity of the fire itself, and the effect is always to oppose, and therefore to reduce the ventilation.

b. **Buoyancy** - this effect is due to hot air rising and being replaced by descending cold air. The buoyancy effect is associated with the gradient of the airways in the fire area. Its effect is minimal in level roadways and maximum in vertical shafts.

The buoyancy pressure generated by a severe timber fire in a roadway inclined at 1 in 2 would be about 0.5 kPa in the first 400 m downstream of the fire. The build-up of buoyancy pressure falls off downstream as the fumes cool. Buoyancy has the same effect as a booster fan installed in the ventilation circuit, blowing uphill. This means that an ascending ventilation current is boosted by the effect of a fire, whereas a descending air current is reduced or even reversed by the fire. It also follows that a fire at the bottom of an inclined roadway or shaft would have a far greater effect than a fire located at or near the top of the same shaft or roadway.

Examples of the buoyancy effect of fires are shown in Figures 2-5, 2-6 and 2-7. The situation shown in Figure 2-5 has arisen in a Nova Scotia mine.

The buoyancy effect can be very strong and can cause total disruption to the mine ventilation. In an extreme case (Black Heart Mine, Belgium) a fire in the downcast pit bottom reversed the ventilation throughout the mine and in the shafts themselves. Air was sucked backwards through the exhausting fan on the upcast pit top which was running at 1.5 kPa at the time.

In the event the main fan stopping during a fire incident, the mine ventilation system can be taken over almost completely by the buoyancy effect of the fire. There is a complete loss of control of the system and a highly dangerous situation can arise.

2.6.7 Smoke and Recirculation

All fires cause a considerable temperature gradient between the air at the roof of the roadway, and the air near the floor. This causes a layering effect of smoke and fire gases and it is quite possible for a roof of a roadway to be enveloped in dense smoke while there are clear air conditions at floor level. In level roadways this layering effect is prevalent for considerable distances downwind of the fire, but there is also a backing of the smoke layer against the ventilation current upwind of the fire. This layering is particularly persistent in inclined airways where the ventilation is downhill.

A development of the smokebacking phenomenon is the creation of two separate air currents in one airway, particularly if

inclined. There can be a brisk current of fresh air going in one direction at floor level, and another brisk current of hot air, gases and smoke, going in the other direction at roof level with a clear line of demarcation between the two. This can be intensified if there are lines of steel ventilation ducts at roof level, or a clear passage for air above the roadway supports and linings. In an example at a recent fire in a slope drivage at 1 in 4, the downhill flow of fresh air was measured at 10 m^3/sec at floor level and a corresponding flow uphill of smoke and hot air at roof level.

If the fire intensifies still further, the re-circulation phenomenum will increase to include whole districts, airways or even the whole mine.

2.6.8 Falls

A major fire in a mine roadway will eventually burn away and weaken the support system. It will also dry out and fracture roadside strata.

This may lead to minor or major falls of ground. The following hazards arise:

- danger to personnel fighting the fire
- obstruction of access to the fire area
- obstruction and disruption to the ventilation system
- deposition of a mass of burning material at floor level
- production of blazing cavities at the roof and sides of the road.

This phenomenum is present in the fire area itself and in the area immediately behind the fire as it advances downwind. This means that fighting a fire from the intake side may have to be

abandoned, as it becomes too dangerous for firefighters to work under an unsupported roof.

2.7 FIRE FIGHTING OPERATIONS

2.7.1 Principles

For combustion to continue a fire requires the continuous availability of fuel, oxygen and heat. When one or more of these factors is removed combustion will be stopped.

Fuel can be limited by starvation. Starving a fire means removing the available fuel, for example by draining fuel from a burning fuel tank. Alternatively, the fire may be moved away from combustible materials. This is attempted in the 'digging out' process which is occasionally used in mines (see 2.7.3 below).

Heat is limited by cooling. Cooling is a most effective way of extinguishing a fire, since combustion cannot continue when the materials which are burning are cooled below the flash point. This means that the fire must die away when the rate of heat production is exceeded by the rate at which heat is removed.

In this respect, water is a most effective coolant since large amounts of heat are absorbed in raising its temperature to boiling point and during the process of converting water into steam. It takes about six times as much heat to convert a given amount of water at its boiling point to steam as is required to raise its temperature up to boiling point. For this reason water is an effective fire fighting medium and should be applied to a fire in such a way that as much as possible is converted into steam rather than running away as free (but very hot) water. Steam formed in the early stages of a fire when the heat is considerable,

will not be visible, but as the temperature of the fire falls, the steam will condense above the fire, a sign that it is being brought under control. However, if water is directed onto incandescent burning coal in a confined or unventilated space, the water reacts with carbon to form a mixture of hydrogen and carbon monoxide called water gas. Such a mixture of gases is highly inflammable and can be ignited by the burning materials, sometimes with explosive violence. A spray will cool the flames without reacting in the above manner. A concentrated water jet should not, therefore, be used in a confined space. It should be applied only on ventilated burning surfaces.

Oxygen is limited by smothering. The process of smothering a fire requires the exclusion of oxygen. This is usually achieved by stopping the flow of fresh air to the seat of the fire so that the combustion process or the emission of other gases, e.g. methane, reduces the oxygen content and the fire is extinguished. This is the objective in the process of stopping off or erecting fire seals and is the basis of the inerting process. The same effect can be achieved in small fires by smothering with dry sand or stone dust or by using foam type extinguishers.

2.7.2 Direct Means of Fighting Fires

All small fires and the early stages of large fires should be tackled by direct means. The action should be prompt and resolute, but with appropriate safety precautions, including, for example, isolating electric power supplies and leaving an escape route. Sufficient resources of men or materials are essential. Self-contained fire extinguishers are suitable for use on small fires.

Even a roadway which is well alight may be tackled directly by using water. In fighting a medium sized fire, the aim always should be to approach the fire from the upstream (intake) side. The return side of the fire is usually too hot to approach and it is only safe to approach by men wearing breathing apparatus. In order to mount an effective attack there must be sufficient water pressure in the fire fighting pipe range to operate several branches simultaneously.

There are a number of hazards encountered during direct fire fighting. There is the danger of the effects of heat and fire fighters should frequently change duties so as to limit the time of exposure. Coldness can be a problem because of strong air currents in the mine and waterproof clothing is, therefore, required. There is a smoke hazard that can be reduced by erecting brattice sheets to induce a strong ventilation flow at the roof of a roadway to prevent smoke layers forming or backing up. Variable spray nozzles have been found to be effective in forming a water curtain against smoke. An effective stream of cool fresh air can often be brought to the firefighters by laying ventilation ducting to a fresh air source.

If the fire fighting range, which should be a minimum of 64 mm in diameter, and preferably 100 mm to 150 mm diameter, passes through the fire area, the heat can change the water in the pipe to steam causing a very high pressure. Unless suitable precautions are taken, when the hydrant valve is opened, the flexible hose can be filled with high pressure superheated steam that can burst the hose and envelop the fire fighter in scalding steam.

As the fire develops, the most serious threat to the safety of the fire fighting team is the possibility of falling roof, often consisting of burning materials. It is this threat which usually limits

attempts to deal with the situation by direct means and necessitates resort to indirect methods.

2.7.3 Digging Out

This is a term which means the removing of smouldering or burning material from a fire area, and is usually related to the damping down stages of open or spontaneous combustion fire which is thought to be very near the roadside. Digging out is not recommended because it is unpleasant and dangerous and the transport of the removed material is difficult. The process is usually ineffective since frequently the fire fighters are certain that the seat of the fire is within their reach, but as they advance they find the fire zone has receded. The dug out material can burst into flames over a large area. Digging out should only be attempted when the location of the seat of the fire has been clearly defined.

2.7.4 Indirect Means of Fighting Fire

Lining

Lining is often an effective way of stifling a deep seated heating and involves applying an airtight seal to the roof, sides and floor of the mine roadways in the vicinity of the incident. One method is to erect a lining of boards, blocks or metal sheets behind the supports of the roadway and to fill in the space between this lining and the strata with tightly packed sand or plaster. Where the road is supported by arched girders, the lining can conveniently be formed by placing close fitting wooden boards in the web of the arched girder over its circumference. In some cases a second line of supports can be erected inside the original

support system to give a very smooth lined road when filled in by boards and backfilled. This is known as double lining or boxing.

When the sides and roof of the roadway are solid and stable, a spray lining is, perhaps, the quickest and most effective. Typical materials which can be used for this purpose are mixtures of cement or gypsum and fillers. Such materials are sprayed on using a special mixing and pumping machines with a short hose terminated by a nozzle. Such machines can spray about one tonne of dry powder per hour, mixed into a slurry form. Pneumatically operated machines perform the same function at a somewhat higher rate. It is difficult to achieve a truly airtight seal by the spraying technique if the roadside is heavily fractured or irregularly timbered. In all cases of lining, attention is required from time to time afterwards to ensure that the lining remains unbroken.

Lining should commence at least 10 m upstream of the incident spot and continue for a further 10 m beyond. This means that the minimum length is about 20 m though often large continuous lengths of roadways are treated, and in some cases the lining is continued as the working face advances.

In addition to the treatment of the sections of roadway where gob odours or smoke are apparent, lining is most effective in stretches of roadway where air is leaking into a fire.

Injection

Injection involves contacting all the breaks and cavities in the strata which are leading to and from the suspected fire area and filling these breaks with slurry type materials. This is achieved by systematically drilling into the strata. The first 1.3 m or so of

each drillhole is drilled with a 60 mm (approximately) drill bit, and a 1 m standpipe is inserted. Grout is then injected to fill up any breaks contacted and to seal the standpipe. When the pipe is firm, the hole is continued, boring through the standpipe with a smaller bit. Each of the holes is drilled to about 4 m in length or until the major breaks have been contacted. The injection of slurry is then repeated until there is no further flow of slurry into the strata.

A rectangular pattern should be attempted, e.g. 2 holes on either side of the road and 2 into the roof; not forgetting 2 further holes into the floor to check for floor breaks. This drilling pattern should be repeated at about 5 m intervals over the affected or suspect lengths of roadway. This ensures that a good length of consolidated ground is formed. Again, a minimum of 20 m applies as the need to treat both intake and return accesses to the fire area.

A variety of materials can be used in the preparation of the slurry, whose principal property should be the ability to act as a permanent solid filling in any breaks but on the other hand, the slurry should be able to move considerable distances through small breaks, so that a viscous property is also required. Materials commonly used are mixtures of cement and stone dust or other proprietary materials based on cement or fly ash. Gypsum plaster is not such a suitable material for this purpose, since it does not travel far before setting, and also disintegrates into dust when subject to the high temperatures which may be encountered. On the other hand, bentonite (Fullers Earth) has the ability to travel long distances in the strata, but tends to slump away over a length of time. An extensive range of grout pumps are available having capacities ranging from 2200 L/h to 8000 L/h at pressures ranging from 1100 kPa to 5000 kPa. The minimum installation for

injection usually consists of a mixing tank feeding a high pressure pump.

Inerting

This method can be classed as an indirect means of fire fighting. It is fully discussed in this report.

Stopping Off

Stopping off means plugging all roadway accesses leading to and from the fire area with dams, seals, or stoppings so that it becomes impossible for any air to reach the fire, or any of the products of combustion to be emitted into the ventilation. The fire is thus smothered by depriving it of oxygen.

The advantages of stopping off are primarily that of safety as stoppings are usually erected at least 150 metres away and in some cases can be as far as 1 km to 3 kmfrom the fire.

It is also efficient in terminating what may have become a serious or prolonged fire situation which has not responded to other methods of treatment. Stopping off is often a permanent cure and the chances of further serious trouble are small. Stopping off can be cheaper than prolonged treatment by labour intensive methods.

However, there are serious disadvantages including the almost certain loss of large amounts of capital equipment in the sealed area, the loss of working reserves of mineral and the sterilization of development areas. The control of a fire sealed area is also difficult in broken ground, and the recovery of a district once sealed can be difficult and may be unsuccessful if a fire,

particularly spontaneous combustion, has been involved. The establishment of a large sealed area in a mine brings with it other implications for ventilation and water control.

A stopping should be airtight and this can be achieved by the construction of a brick or block wall, or even a wooden structure. Where any signs of fire has been, or may be present, then an explosion proof stopping is required. These can be massive constructions of sand or other materials about 8 m to 10 m long, or more usually walls about 4 m to 5 m apart filled with cement or gypsum plaster materials. The length of the stopping should be slightly greater than the average of the width and height of the roadway in which it is erected. Since the plaster and block materials are not always available, many stoppings are placed with mine dirt obtained locally and placed between packed walls. This type of stopping is neither airtight nor explosion proof.

The proper selection of the stopping sites is most important and should be undertaken both from a careful study of the full working plans of the mine, to ensure that every access to the fire is properly sealed and to ensure that the stoppings will not be bypassed by unconsolidated ground or old roads etc. and from a careful examination of the selected sites underground by an experienced person to make sure that the strata is solid where the stopping is to be constructed, and that heavy structures such as conveyor drives are avoided.

The walls of a stopping can be made of any materials which will contain the plaster fill until it sets solid. Sand bags, bricks, blocks, wood or metal shuttering have all been successfully used. The inclusion of access tubes is most important as they permit a continuing flow of ventilation round the district whilst the stopping is being completed, thereby virtually eliminating the risk of

explosion, and permitting examination of the inbye wall whilst the stopping is being constructed. Typically access tubes varying from 500 mm diameter to 2.2 m x 2.2 m are used, often incorporating a massive explosion proof inbye door to facilitate rapid closure and the possibility of future re-entry into the sealed area. Air sampling tubes and water or gas drainage pipes are usually left through the stoppings.

The plaster filling material is either of the gypsum or cement based type. Bulk filling additives such as fly ash or sand are often included. The plaster mix is supplied from special placer machines which consist essentially of a metered mixing compartment feeding to a high pressure pump. According to the type of machine used and the type of plaster material, the placer can be situated from 20 m to 1000 m from the stopping site, 50 mm to 64 m diameter hose being commonly used to transport the plaster mix which has a variable setting time from 10 minutes to over one hour.

The key to the construction of the stopping is the preparation of the walls and the installation of fittings. The walls should be built on a firm foundation and should be made leak proof on each side and especially into the roof. This may entail removing covering sheets and timber and loose strata. Whilst this work is in progress, sufficient quantities of plaster powder should be brought to the placer position to complete the stoppings, allowing for loss due to leakage. This work often takes about one day to complete. Once pumping starts, it should be continuous as far as possible as interruptions tend to lead to the setting of the plaster in the machines and pipes and other mechanical troubles. Should there be an interruption, the machine pipes should be immediately flushed out with fresh water. It is important that the stopping is topped up with plaster right up to the roof of the roadway. This

can be a difficult operation and it usually takes several hours to complete the last 0.5 m of the stopping, due to leakage at roof level. It is often necessary to pump through a probe pipe which delivers plaster to the highest point in the stopping. The final job is to seal the access tubes in all stoppings at the same time. Following the final sealing, it is usual for the mine to be abandoned for up to 24 hours to avoid the risk to personnel whilst the sealed atmosphere passes through the explosive range.

After the mine is re-opened, a continuing control of the stoppings is required to ensure that they remain secure and airtight and that air samples are taken at regular intervals from behind all stoppings, and in the local airways to monitor the fire activity which has been sealed off and any possible pollution of airways as a result of leakage from the sealed area.

2.7.5 Practical Aspects

Smoke control is a prerequisite for any fire fighting operation and suitable arrangements must be made when fire fighting activities are being prepared.

If a fire fighting range passes through a fire area water may be turned to steam which could be released under high pressure onto the fire fighters. Special mechanical contrivances, or the controlled opening of hydrant valves can minimize this hazard.

Fire fighters may become soaked with water and be badly affected by coldness on the way out of the mine. For this reason a supply of waterproof gear, dry overalls and dry blankets, should be provided for fire fighting teams.

Because of their special training, rescue men may be used as fire fighters both in fresh and polluted air. Except in life saving

situation, standard rescue procedures must be observed to ensure that the rescue teams work in safety. There are limits to the capabilities of rescue men. Rescue procedures require that the operational times of rescue teams becomes increasingly limited with increasing temperature and this fact should be included in any rescue team roster which is prepared.

2.7.6 Pressure Balancing

Where a fire is controlled by sealing off, the reduction of air leakage into the sealed area is critical. If leakage is persistently troublesome, then pressure balancing may be applied. The technique involves the construction of an airtight wall at least 5 m in front of the main stopping, and a positive or negative air pressure is artificially induced inside it by means of a duct system. The duct leads to a remote fan, or by taps into a suitable mine ventilation pressure elsewhere. The pressure across the main stopping from the sealed area to the artificially formed chamber is brought to zero. Leakage across the main stopping will cease. Techniques are available by which the pressure in the pressure chamber can be automatically adjusted to ensure consistently stable and static conditions.

2.8 FIRE PRECAUTIONS

2.8.1 Introduction

Many planning and operational factors contribute to minimize fire and related major hazards at a mine. Several of the factors are discussed below, not necessarily in order of priority.

2.8.2 Mine Planning

Many mining hazards can be eliminated during the planning of the mine layout and its working methods. A careful study of a proposed development plan can reveal points of weakness that could be conducive to or aggravate an incident. This particularly applies to the prevention of spontaneous combustion incidents.

2.8.3 Fire Fighting Arrangements

All parts of a mine must have efficient fire fighting installations. On the surface, sufficient water supplies from a reservoir or from pumped sources must be available. Fire fighting ranges must be of adequate size, preferably 100 mm and 150 mm diameter with strategically placed hydrants, hoses and control valves. All intake airways and as much as practicable of the return airways in the workings districts should be equipped with fire fighting ranges.

2.8.4 Education and Training

Mock emergencies are a most valuable method of teaching and checking emergency arrangements. There should be instructions on the alternative means of egress from the mine and the working of the Mine Emergency Scheme. Periodic discussions and briefings should be held with supervisors and hourly paid employees.

2.8.5 Ventilation Contingency Plans

When a sudden emergency arises, it is virtually impossible to assess the implications to the mine as a whole. Preparations for these events can be made by preparing contingency plans for incidents in various locations on the ventilation system and for other emergency situations. This work can be assisted by

computer exercises that will show the most dangerous situations and the potential remedial steps.

2.8.6 Stone Dust Barriers

The value of stone dust barriers cannot be over emphasized in limiting the spread of mine explosions. The installation of stone dust barriers should be liberal, their conditions should be regularly checked, and they should be moved forward as the workings develop. Additional barriers should also be erected as a safeguard during the course of an incident. Water trigger barriers perform the same function but are still undergoing technical development.

2.8.7 Fire Proof Zones

Fire proof stretches of roadways may be constructed with the aim of containing any major fire to certain sections of the mine or roadway. Because of the thermal transmission by the ventilation, such zones typically have to be 100 m to 200 m in length and must be completely free of combustible materials including flammable conveyor belting. This technique justifies further research.

2.8.8 Isolation Doors

The installation of explosion proof and fire proof isolation doors which can be closed following a severe incident, serve a similar purpose to the fireproof zone. They also restrict the products of combustion from polluting other ventilation circuits and so assist access and escape. Such installations are expensive and require careful design so that obstacles such as belt structure or rails can be quickly dismantled allowing the doors to be shut in an emergency.

2.8.9 Mine Emergency Scheme

Development of a Mine Emergency Scheme is a prerequisite to any disaster planning. The Scheme should be designed in detail to provide for safe withdrawal of men from the affected part, immediate attempts to treat the incident on the spot, notification to the surface, and progressive build-up of resources to deal with the incident.

2.8.10 Mobile Laboratory Facilities

A scientific back-up service is essential to the control of an incident, particularly in relation to the rapid and accurate analysis of air samples, and the interpretation of the analytical results. It is not always possible to have a sophisticated scientific control at each mine, but a mobile system should be available and kept in a state of constant readiness to be taken to any incident. This can take the form of a mobile laboratory or of transportable units which can be taken by truck or plane and installed at a suitable location in a mine. The mine should prepare for the arrival of the units by having services of water, power and telephone previously supplied to the selected laboratory site or office.

2.8.11 Prepared Stopping Sites

Stopping sites should be pre-selected so that they could contain any major incidents. It is preferable that primary sites are selected inbye, together with secondary sites further outbye, to contain a larger incident, or as a line of retreat should this be necessary. Sites with good access for men and materials should be selected, since the return airways may not be available for men or material transport because of smoke or pollution. In some

cases these stopping sites can be partially prepared to ensure that stopping off can be rapid if their use is called for.

2.8.12 Self Rescuers

Self rescuers carried by mine workers have already been responsible for saving many hundreds of lives underground and their universal use is recommended. Simple filter type rescuers which remove carbon monoxide serve most purposes, but rescuers and escape sets which contain a supply of oxygen are even more useful but tend to be heavy, expensive and more difficult to maintain. The issue of self rescuers necessitates a good standard of initial training and regular refresher courses.

2.8.13 Mines Rescue Service

The Mine rescue services and the public emergency services need to be involved in any contingency planning for a major event. Not only will they be able to give good advice and information concerning the most effective way in which their services can be used, but they need to be informed of the various accesses into all parts of the mine. Because of smoke or damage, they may have to gain access to the affected area from shafts or drifts which are many kilometres away, and the rescue organization needs to be prepared for such an event.

2.8.14 Ventilation Monitoring

In theory, comprehensive monitoring systems will give immediate display and print-out information on the state of the ventilation and the level of impurities at that particular moment of time for all significant parts of the mine. If this was so, then such a system would be invaluable in giving warnings of impending events

or give an accurate picture of the effects of a fire incident, and thereafter show the progress or otherwise of the containment of the incident.

In practice there are many occasions when this does not happen, and the information can be two or more hours out of date, incomplete, or erroneous due to pollution or dilution of the samples analysed or faulty hardware and software. Such a situation can lead to misreading of the situation with possibly dangerous results. Extreme care must, therefore, be taken in accepting or interpreting information from monitoring systems and the reading should be backed by routine analysis of air samples taken by hand or from the readings of reliable on-the-spot instruments.

Nevertheless, once a monitoring system has been 'tuned' to an incident, then the benefits in safety and efficiency are considerable.

2.8.15 Communications

Communications problems are always the most difficult at every major incident. The problem hits hard at all levels, ranging from the human aspect of being able to contact the people you want to, when you want to, and ensuring that the information and instructions passing both ways are properly understood. On the technical side, there is always a problem of having sufficient numbers of telephone lines and radio channels available to deal with the vast amount of traffic passing between specific points. Very often the communication system gets completely blocked and breaks down. Finally, there is a need to have the correct sort of communication system for the type of incident, e.g. telephone and teleprinter facilities, mobile radios and pagers for travelling personnel.

Communication problems can be designed out in the planning stages to a large extent by allowing spare capacity to greatly increase point-to-point contact if needed. Emergency communication equipment should be held by rescue services to supplement heavily loaded systems during emergencies.

2.8.16 Incident Management

Efficient management control is fundamental to the effective treatment of major or minor incidents. The levels of responsibility and lines of command should be establishing beforehand. A system of overall control must be arranged for incidents which affect several mines and the structure should be able to accept the additional and unfamiliar services and people who become involved at an incident.

The management structure included in any emergency scheme must take into account that certain management staff may not be available at the time of the incident.

A fundamental principle of any emergency scheme is that at all times an identifiable controller is in charge of the incident. In performing his duties he should be assisted by an incident control committee representing all interests and expertise relevant to the particular stage of an incident.

Apart from the initial stages of an incident when continuous attention of all those who are available and competent to help is required, the control of the incident should be agreed at specially called policy meetings at appropriate regular intervals, and in the intervening periods the controller with a small team of operatives and advisors should implement the agreed plan.

2.9 REFERENCE MATERIAL

Further information on many of the topics addressed in this section can be found in the following publications.

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1952 **Limits of Flammability of Gases and Vapours**; USBM Bulletin

Hughes, A.J. and Raybould, W.E.
1960 **The Rapid Determination of the Explosibility of Mine Fire Gases**; Min.Eng. (UK), October

Blackwell, J.R. and Roberts, A.F.
1969 **The Possibility of the Occurrence of Fuel Rich Mine Fires**; Min. Eng. (UK) September

Robinson et al.
1972 **The Fire at Ogilvie Colliery**; Min. Eng. (UK) September

Anon
1966 **The Report on the West Virginian Colliery Disaster**; Colliery Guardian, Feb 4, p 147.

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1961 **The Application of Pressure Balancing Chambers to Control Air Movement in Sealed Areas**; Min.Eng. (UK) August.

Yates, D.C.
1969 **The Automatic Control of Pressure Balancing Chambers**; Min.Eng. (UK).

Anon
1962 **Memorandum on Sealing Off Fires Underground;** Inst. Min.Eng. (UK).

Thurton, F.B.
1981 **Colliery Explosions and Fires. Their Influence upon Legislation and Mining Practice;** Min. Eng. (UK).

FIGURE 2-1

DEVELOPMENT OF SPONTANEOUS COMBUSTION

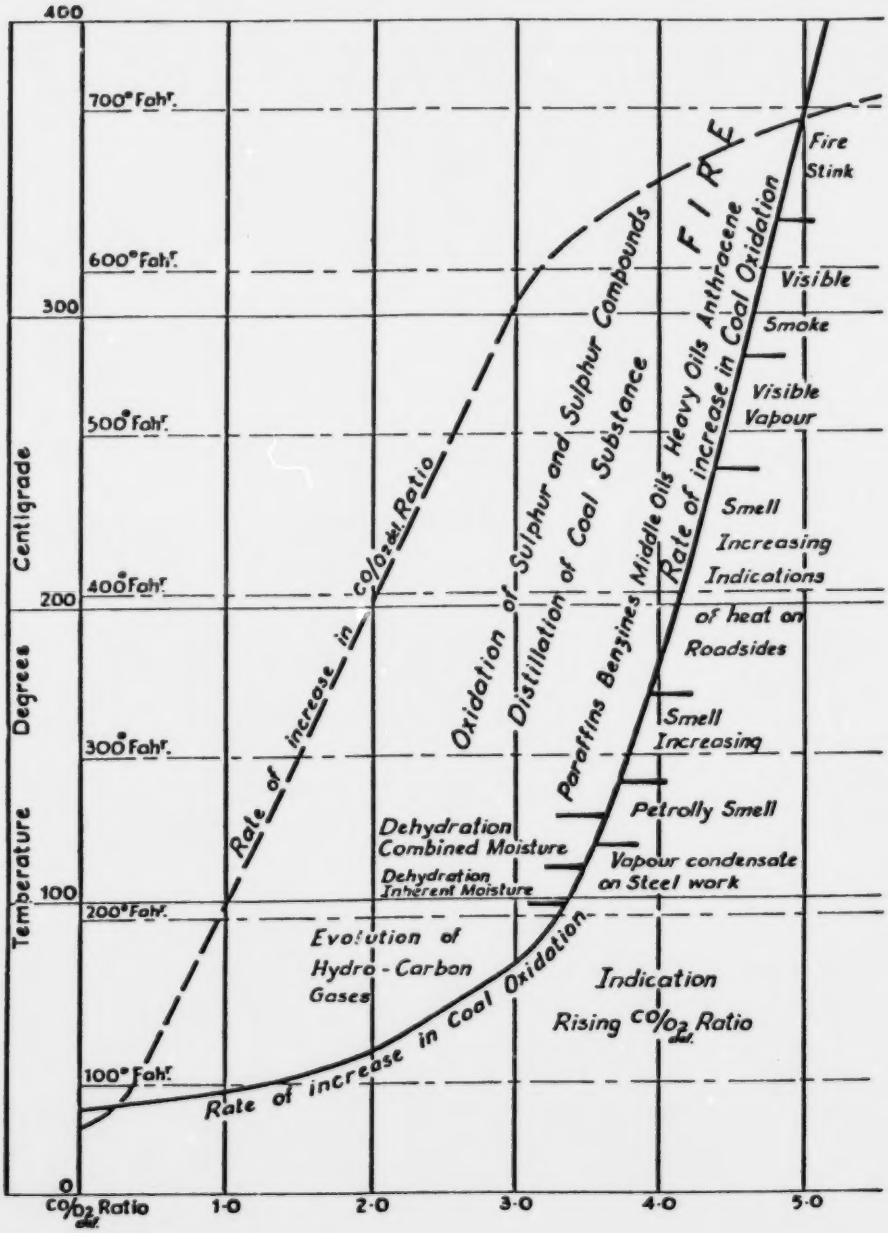
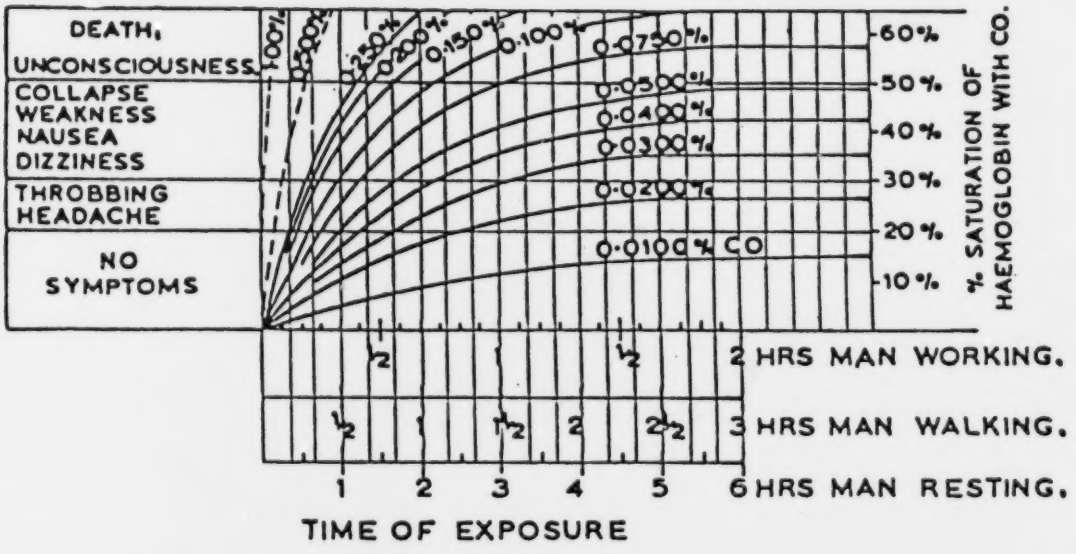


FIGURE 2-2

EFFECT ON MAN OF VARIOUS CONCENTRATIONS OF CARBON MONOXIDE



NOTE:- 0·0001% = 1 PART PER MILLION (P.P.M.)

FIGURE 2-3

EFFECTS OF MINE FIRES

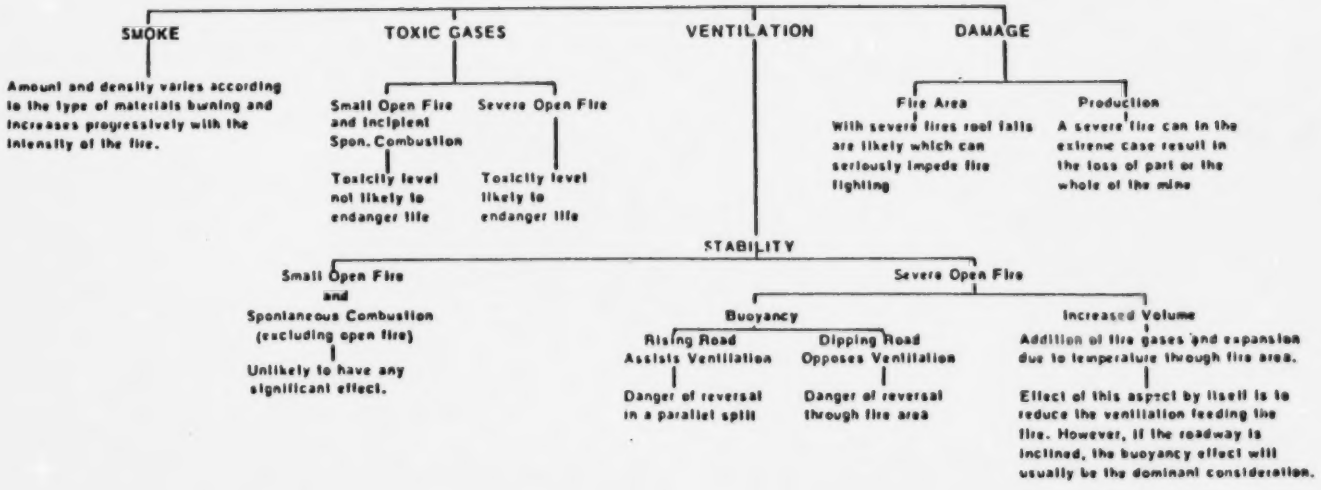

SMOKE
TOXIC GASES
VENTILATION
DAMAGE
Amount and density varies according to the type of materials burning and increases progressively with the intensity of the fire.
Small Open Fire and incipient Spon. Combustion
Severe Open Fire
Toxicity level not likely to endanger life
Toxicity level likely to endanger life
Fire Area
Production
With severe fires roof falls are likely which can seriously impede fire fighting
A severe fire can in the extreme case result in the loss of part or the whole of the mine
STABILITY
Small Open Fire and Spontaneous Combustion (excluding open fire)
Unlikely to have any significant effect.
Severe Open Fire
Buoyancy
Rising Road Assists Ventilation
Dipping Road Opposes Ventilation
Danger of reversal in a parallel split
Danger of reversal through fire area
Increased Volume
Addition of fire gases and expansion due to temperature through fire area.
Effect of this aspect by itself is to reduce the ventilation feeding the fire. However, if the roadway is inclined, the buoyancy effect will usually be the dominant consideration.

FIGURE 2-4

COMPOSITION AND EXPLOSIBILITY OF MIXTURES OF METHANE, OXYGEN AND NITROGEN

(Inflammability triangle - after Coward)

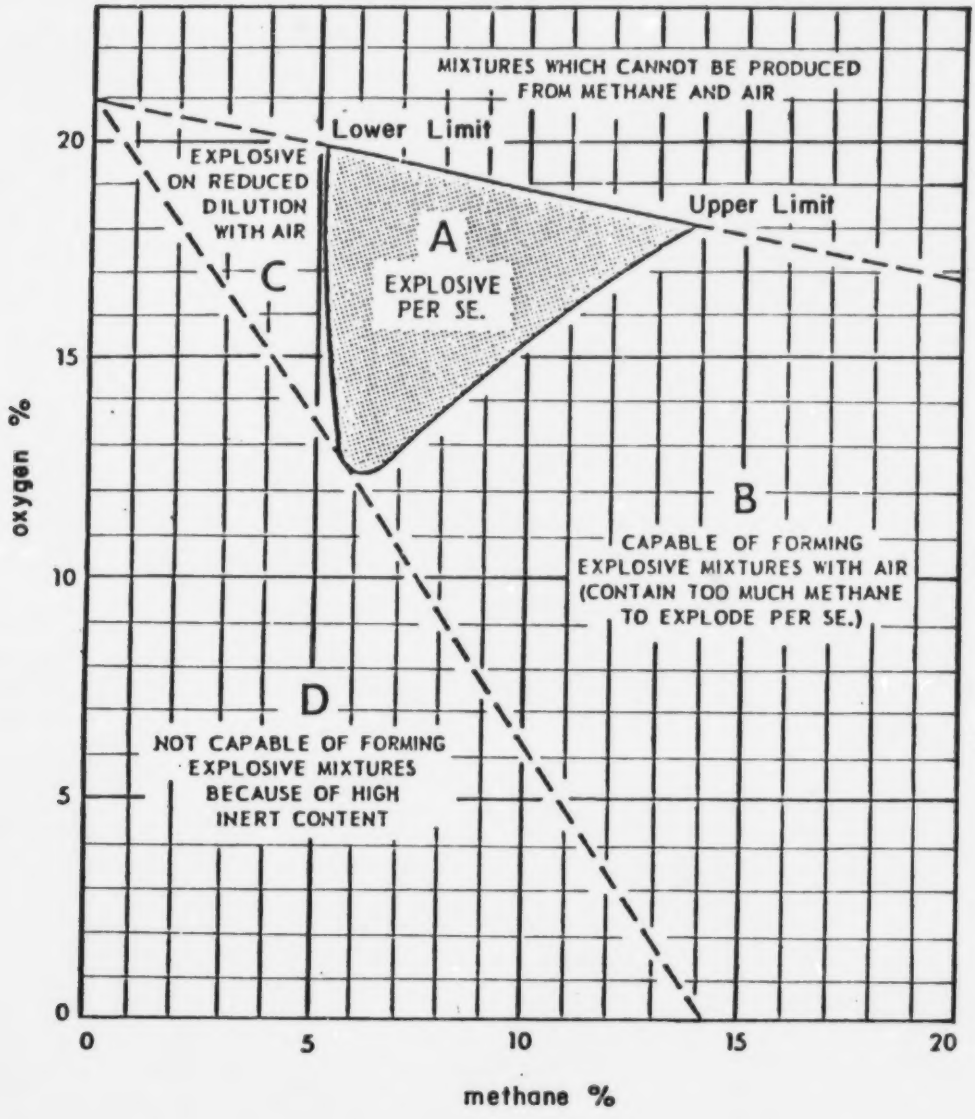


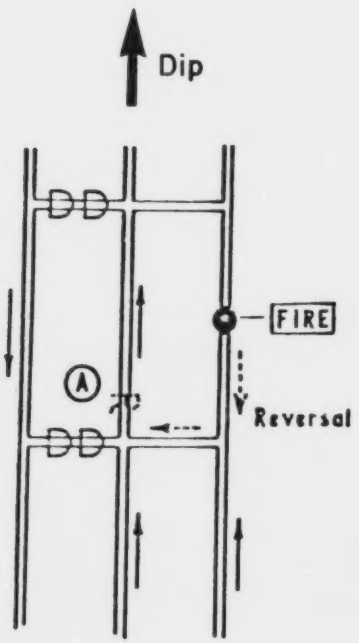
FIGURE 2-5

SEVERE FIRE IN INCLINED 2-ENTRY ROADWAYS

Note: Risk of reversal if,
a) Doors 'A' sealed
b) Main Fan stopped

FIGURE 2-6

SEVERE FIRE IN DIPPING 3-ENTRY ROADWAY

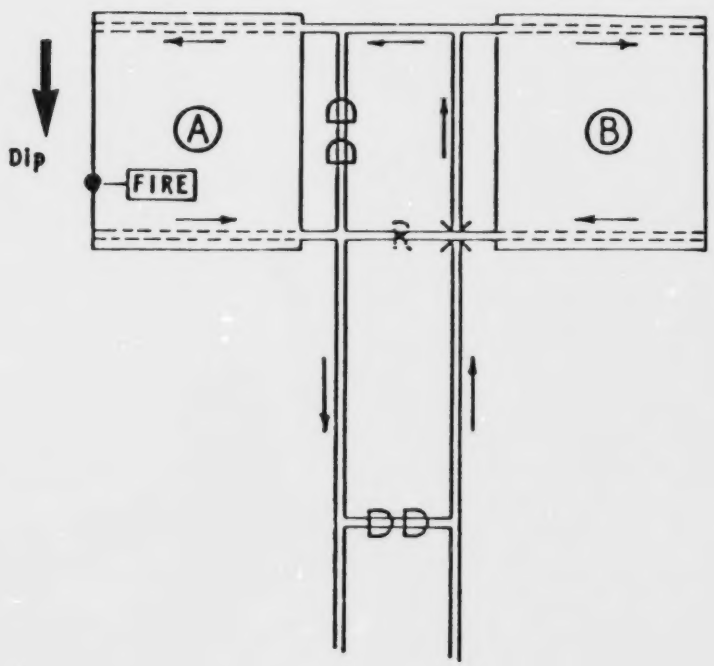


Note : Danger of reversal through fire area resulting in
a.) Increasing ventilation in adjacent intake
b.) Some recirculation of the fire gases

Action Install regulator at point 'A' to maintain stability of vent.

FIGURE 2-7

FIRE ON DESCENSIONALLY VENTILATED LONGWALL FACE



Note: Fire will reduce and possibly reverse ventilation in District (A) and increase ventilation in District (B)
Regulators necessary in (B) to stabilise ventilation

APPENDIX B

MINE FIRES

GRAPHICAL METHOD OF DETERMINING EXPLOSIBILITY DATA

When the computer is not available the Hughes and Raybold graphical method should be used to calculate the explosibility data. The necessary graphs are included, Graphs (Figures 1, 2, 3 and 4), together with a report form (Figure 5) proceed as follows:

1. From the analysis calculate (a) the proportion of methane and (b) the proportion of hydrogen in the combustibles.

2. Place a transparent cross cursor over Graph 1 (Figure 1), lining up the percentages of methane and hydrogen in the combustible gases with the scales on the outside of the square. Where the intersection of the two axis of the cross falls on the scale printed inside the square is the combustible gas content of the lower explosive limit mixture with air.

3. In similar manner find the oxygen content of the nose limit from Graph 2 (Figure 2), and the combustible gas content of the nose limit from Graph 3 (Figure 3). The combustible gas content of the upper explosive limit mixture with air is read off the ordinate of Graph 4 (Figure 4) in the usual way.

Mark all these points on the standard Graph (Figure 5) and construct the explosive triangle.

Example:

Actual analysis obtained	%
Carbon dioxide	5.32
Oxygen	11.89
Nitrogen	75.46
Methane	1.93
Carbon monoxide	1.40
Hydrogen	4.00
The combustibles - methane, carbon monoxide and hydrogen - total	7.33
Proportion of methane in combustibles	
$= \frac{1.93}{7.33} \times 100$	26.3
Proportion of hydrogen in combustibles	
$= \frac{4.00}{7.33} \times 100$	54.6
From Graph 1 (Figure B-1), lower explosive limit in air, combustible content	5.0
From Graph 2, (Figure B-2), nose limit oxygen content	6.9
From Graph 3, (Figure B-3), nose limit combustible content	5.4
From Graph 4, (Figure B-4), upper limit in air, combustible	34.6

The Hughes and Raybold method gives a most important facility for determining the nature of the fire gases and is an essential safeguard to the safety of personnel fighting the fire, and gives a strong indication of the safest and most efficient way of combatting it.

FIGURE 1

UNDERGROUND COAL MINE FIRE CONTROL WITH INERTING SYSTEMS

GRAPH 1: COMBUSTIBLE CONTENT AT THE LOWER EXPLOSIVE LIMIT OF MIXTURES OF METHANE, HYDROGEN AND CARBON MONOXIDE IN AIR

Carbon Monoxide % = 100 – (%CH_4 + % H_2)

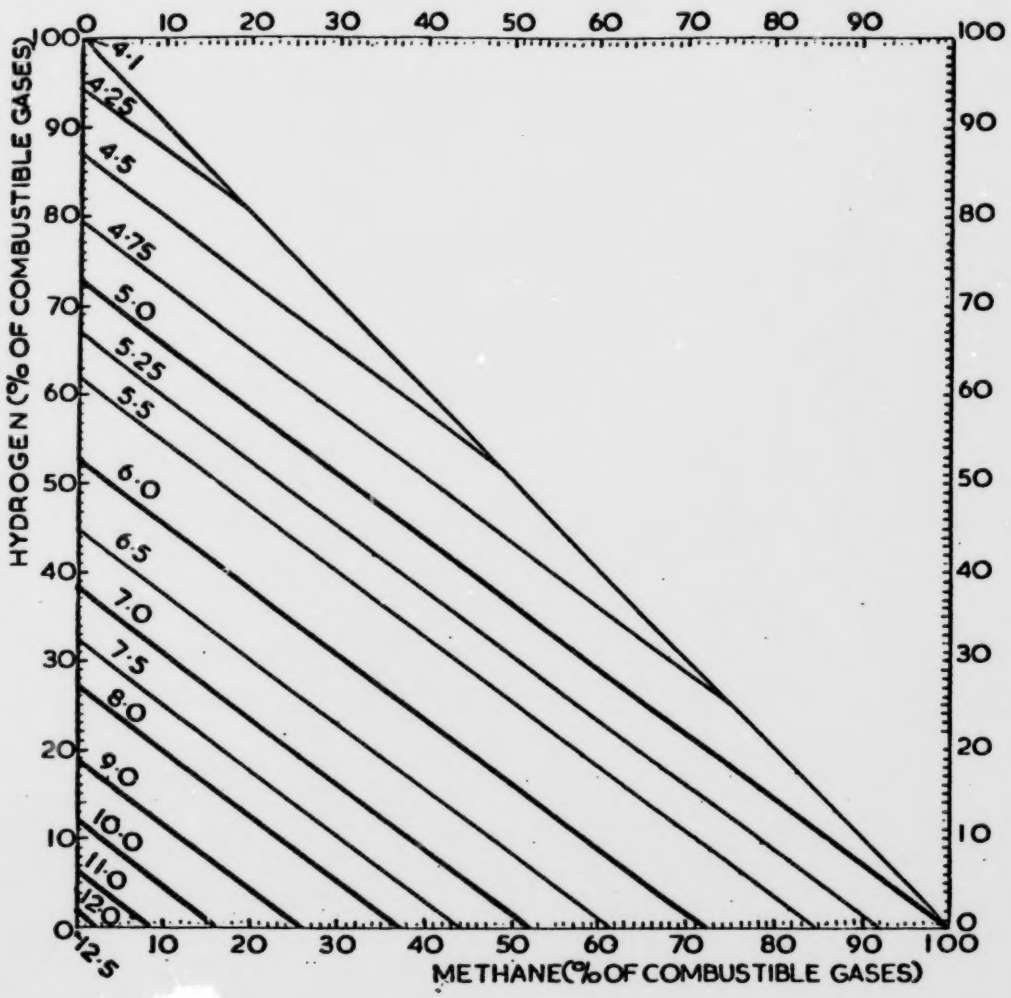


FIGURE 2

UNDERGROUND COAL MINE FIRE CONTROL

WITH INERTING SYSTEMS

GRAPH 2: OXYGEN CONTENT AT THE NOSE LIMIT OF MIXTURES OF METHANE, HYDROGEN AND CARBON MONOXIDE IN AIR AND EXCESS NITROGEN

Carbon Monoxide % = 100 – (%CH_4 + % H_2)

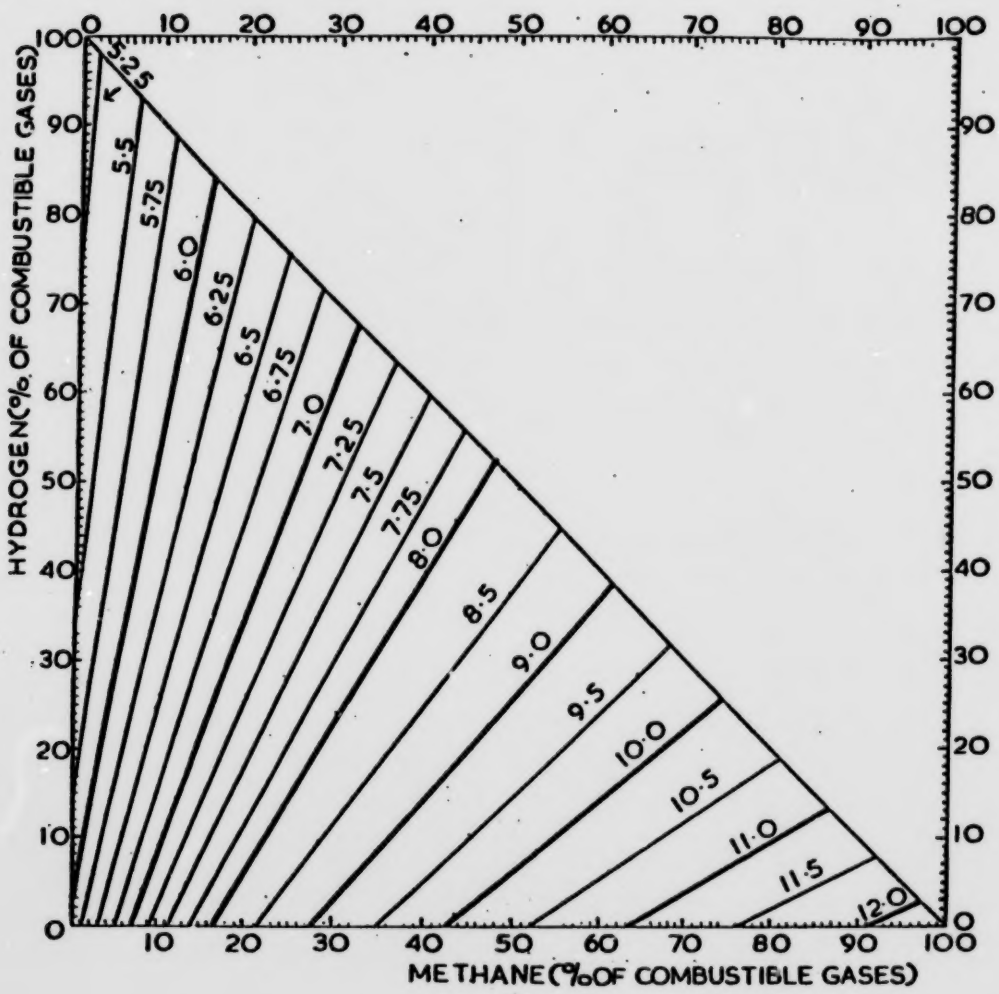


FIGURE 3

UNDERGROUND COAL MINE FIRE CONTROL

WITH INERTING SYSTEMS

GRAPH 3: COMBUSTIBLE CONTENT AT THE NOSE LIMIT OF MIXTURES OF METHANE, HYDROGEN AND CARBON MONOXIDE IN AIR AND EXCESS NITROGEN

Carbon Monoxide % = 100 - (%CH_4 + % H_2)

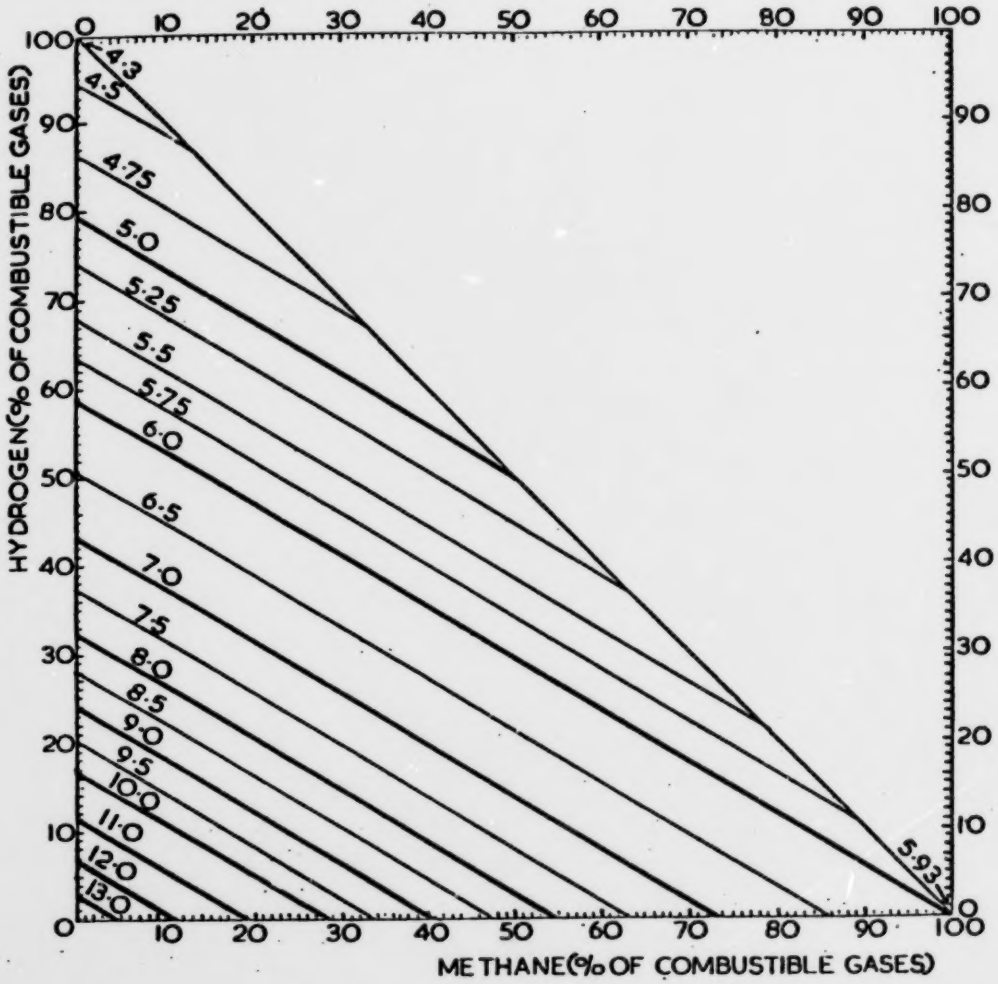


FIGURE 4

UNDERGROUND COAL MINE FIRE CONTROL

WITH INERTING SYSTEMS

GRAPH 4: COMBUSTIBLE CONTENT AT THE UPPER EXPLOSIVE LIMIT OF MIXTURES OF METHANE, HYDROGEN AND CARBON MONOXIDE IN AIR

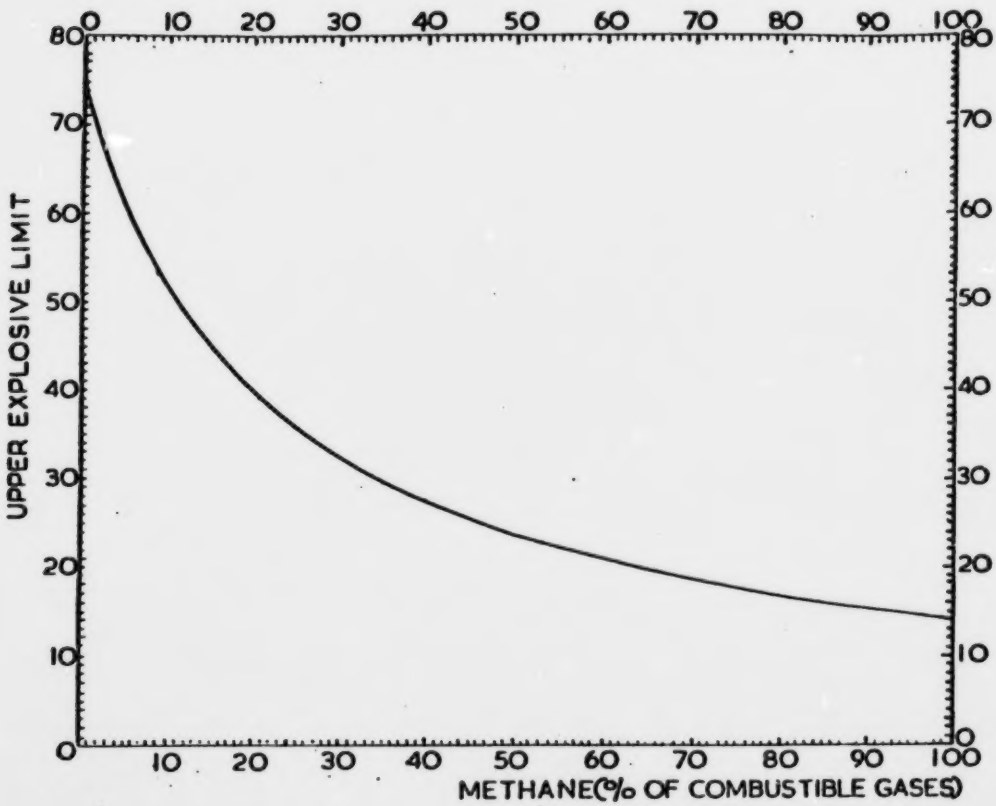


FIGURE 5

UNDERGROUND COAL MINE FIRE CONTROL WITH INERTING SYSTEMS

REPORT SHEET

EXPLOSIBILITY CALCULATION (Raybold & Hughes Method)

1. Colliery :-	2. Date :-	3. Time :-
4. Sample Location :-		

5. Composition of Sample :-

		% By Volume
Oxygen	(A)	=
Methane	(B)	=
Hydrogen	(C)	=
Carbon Monoxide	(D)	=

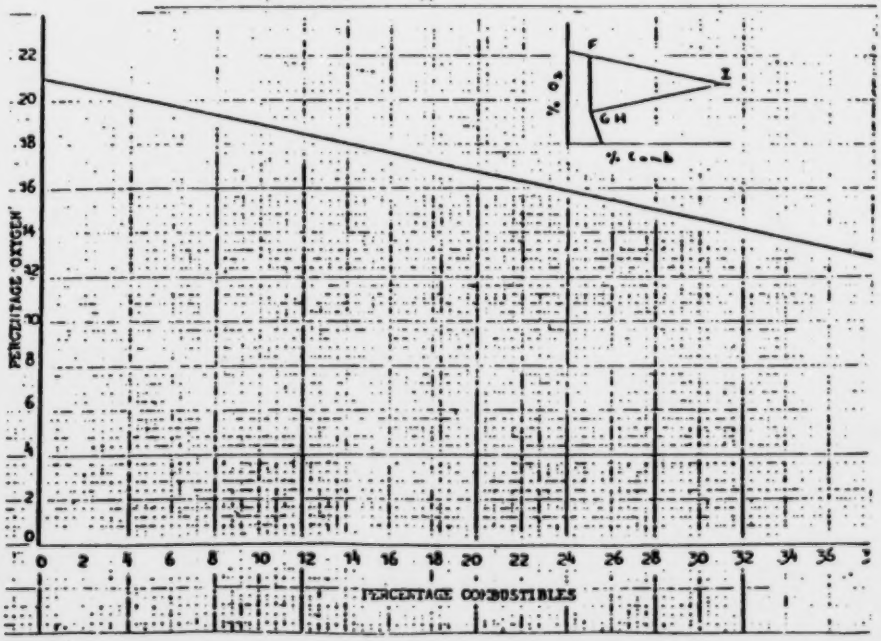
6. Calculation :-

Total Combustibles E = (B+C+D)		=
% Methane in Combustibles = (B/E x 100)		=
% Hydrogen in Combustibles = (C/E x 100)		=
From Fig 2 Lower Combustible Limit	(F)	=
From Fig 3 Nose Limit - % Oxygen	(G)	=
From Fig 4 Nose Limit - % Combustibles	(H)	=
From Fig 5 Upper Combustible Limit	(I)	=

7. Procedure:
   a. Construct Explosibility Triangle from (F)(G)(H) & (I) (See Inset)
   b. Draw Explosibility Boundary from Nose Limit to Combustible Axis such that extension of Line would pass through 20.93 % Oxygen
   c. For Sample plot % Oxygen (A) against % Combustibles (E)

8. _____ :- HAS BEEN
 * EXPLOSIVE / EXPLOSIVE ON DILUTION / NON EXPLOSIVE

* Delete where NOT applicable



AR-72.2

UNDERGROUND MINE FIRE CONTROL

SECTION 3

OPERATIONS OF THE GERMAN MINE RESCUE/FIRE FIGHTING SERVICE

by

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Operations of the German Mine Rescue and Fire-Fighting Services

1. Mine Rescue Services in Germany

Mining in the Federal Republic of Germany has a long tradition. Lead and silver ores were brought to the light from underground mines already more than 1000 years ago. The only minerals still being mined today in sizeable volumes are hardcoal, lignite, potash, and rock salt. In 1983 the following quantities were produced (1, 2)[1]:

81 million metric tons hardcoal,
125 million metric tons lignite, 94 % thereof coming from six opencast mines in the Rhine Area,
22 million metric tons potash and
8 Mio t rock salt.

In addition there are a number of - mostly smaller - mines producing metal ores as well as industrial minerals. Among these should be mentioned:

- iron ore, lead- and zinc ore,
- feldspar, fluor spar, calcite, baryte,
- gypsum, kaolin, slate, quartz sand.

Industrial minerals are mostly extracted from opencast mines.

The mineral oil and natural gas production of the Federal Republic of Germany plays a minor role, due to the scarcity of relevant deposits. It amounted to 4.2 Mio t and 16 Mio cubic meters respectively during 1983. In all of the active mining areas in West Germany work around 117 000 underground miners.

---

[1]The figures in parenthesis refer to the bibliography at the end of the paper.

According to the Statutory Law, effective since 1982, the following categories of operators are obliged either to maintain or to be associated with mine rescue centers:

the operators of

- underground mines,
- production units including fire- and explosion-prone plants,
- production units including plants prone to the occurrence of unrespirable or toxic gases or vapours,
- underground storage units.

Furthermore it is compulsory for every active mine to maintain a mine rescue team, memberschip of which is voluntary.

In the Federal Republic of Germany we have five mine rescue centers whose size and equipment have been adapted to the specific conditions of the different areas covered. These mine rescue centers are responsible for 78 mine rescue teams comprising about 4 200 members who have more than 2 300 oxygen breathing apparatuses of the Dräger BG 174 type at their disposal[3].

2. Mine Rescue Center in Essen

The mine rescue center in Essen is responsible for 26 hardcoal mines within the Ruhr District as well as for one rock salt mine; in emergency cases it also lends assistance to the mines in the Aachen District (Fig. 1). In 1983 the collieries of the Ruhr District plus the Ibbenbüren colliery produced 67 Mio t of saleable hardcoal. The total underground work force consists of 87 000 miners. The coal stems from 160 longwall faces each producing on average 1 550 t/day. The average-sized mine with a daily saleable output of 10 000 t (mean refuse percentage 45%) thus has 6 or 7 operating coal faces. The performance per manshift is over 4 tons. The average mining depth comes to almost 900 m and the mean coalbed thickenss worked to 1.80 m. The normal methane emission is 10 m^3 per ton of coal extracted, with peak emissions as high as 100 m^3.

There are 33 mine rescue teams in the Ruhr coalfield, manned by 2 700 members who account for 3.1% of the underground workers.

Each mine rescue team - of normally 80 members - is headed by an overman who, considering emergency requirements, is assisted by at least three deputies. Each team comprises at least 10 groups consisting of a group leader and four group members. There are about 400 equipment attendants to keep the extensive equipment - among others 1 500 closed circuit devices of the Dräger BG 174 type - in working order. 80% of the team members are equipped with ultra-short wave alarm receivers. On average 15 minutes will elapse between an alarm and readiness for action, which means that at any moment two mine rescue groups or ten people can be set to work, fully equipped, in less than 30 minutes[4].

The mine rescue center in Essen was founded in 1910 by the mining companies of the Ruhr coalfield. Being a division of Bergbau-Forschung the center gets its financial support mainly from the mines of this district. Since 1982 the center is under the superintendence of the mining authorities.

The collieries entrusted the center with the following main responsibilities (Fig.2):

- assistance and supervision of the mine rescue teams and gas protection teams;
- advice to the collieries as far as underground and surface fire protection is concerned;
- development and testing of new equipment and techniques for rescueing and self-rescueing;
- maintenance of an emergency storage including special apparatuses, among others for fire-fighting purposes and rescueing of trapped miners;
- examining and testing of breathing and fire extinction devices.

1 000 experts from the above sectors are trained and retrained every year. The mining authorities and other agencies recognize the mine rescue center as an expert and testing agency.

The mine rescue center maintains a stand-by service. At any moment at least 2 engineers of the rescue team are able to help a mine immediately in case of rescue actions and mine fires. As experts they accompany the rescue teams to the underground site to contribute their advice and practical help to the complex duties of the overman. As members of the surface emergency management they critically influence on the details of rescue actions.

3. Activities of the Mine Rescue Teams

The mine rescue teams intervene after explosions as well as in cases of mine fires and other events where hazardous situations may occur due to noxious gases or lack of oxygen. Rescue teams within the area of the Essen mine rescue center had to intervene 400 times during the past 10 years (Fig. 3).

When comparing the first five years with the second half of this decade, one will notice a decrease in the average number of rescue actions per year from 50 down to 30. 70% of all team actions are inspections of isolated workings, which means regularly scheduled actions. In those areas the oxygen content of the air is mostly rarefied, along with high CH_4 and CO_2 concentrations. Therefore these actions will be thoroughly prepared.

The "surprise" rescue actions mostly have to do with spontaneous combustion of coal. But here, again, the specific number of cases has decreased noticeably. Due to the expansion of inertization techniques the number of to be reopened fire zones has gone down. Fire zones of the classical type which had to be reopened or restricted after a waiting period of several months, have practically disappeared today.

The statistics should, however, by no means give the erroneous impression as if underground mining were approaching zero risk. We are, for example, much concerned about the 25 cases of methane ignitions in mechanized roadheadings, which occurred in our coalfield since 1977. Fortunately, the rescue teams rarely had to intervene in such cases. The same applies to fires generated in roadways with belt conveyance.

4. Scheme of a Rescue Action

Explosions, mine fires, roof breaks in coal faces and roadways, water inrushes, and similar events, require concertated and immediate efforts in order to rescue the miners affected. The entire package of organizational and technical actions to be taken in these emergencies are laid down in a relevant scheme, which was updated in 1984[5]. This scheme is basically applied in all other major interventions by mine rescue teams, too.

The scheme settles among other things:

- Alerting of the persons to be involved in the rescue action;
- immediate actions to be taken by the temporary head of the emergency management;
- the duties of the emergency management;
- the duties of the other persons involved.

The alarm center receives instruction to release an alarm either from the mine management or from the supervising officer on duty. In extreme cases every miner calling from the immediate hazard zone may trigger an alarm[6].

Until the emergency management has been set up it is the temporary emergency leader who initiates the actions to be taken immediately. The mines maintain an emergency stand-by schedule for the persons involved. In case of an alarm the temporary emergency team leader shall not go underground. His duties are listed in Fig. 4.

The operator or his mandataries will take the measures apt to turn away hazards or save accidented persons. The emergency management relies on the close cooperation of representatives of the mining authority, mine management, and mine rescue center. Nowadays the mining authorities will no longer insist on supervising rescue actions although they can, as the case may be, give order to take necessary measures. The duties of the emergency management have been summarized in a check list broken down by categories of duties:

Fig. 5 through 8 contain, in the form of headlines, the measures to be taken in the following categories:

- Safeguarding of underground workers
- Intervention of the rescue team
- Aspects of mine ventilation
- Firefighting

5. Scheme of Mutual Assistance

Notwithstanding the size and efficiency of our mine rescue teams it became obvious that major emergency situations can only be handled with the asistance of neighbouring teams. According to a scheme of mutual assistance, therefore, every mine may request four other teams to come and help[7]. When several rescue teams are simultaneously active at one site, the emergency management will define and delimit the duties and responsibilities of each overman.

6. Flame-Resistant Clothing

In the case of an underground explosion back in 1965 it turned out that five members of a rescue team were fatally burnt although they wore regular flame-resistant clothing. Prompted by these fatalities a procedure was developed allowing the direct assessment of heat effects on man. Several years ago improved flame-resistant clothing was introduced, the protective effect of which is about twice as high

as of previous fabrics. The outfit consists of underwear of a voluminous spongy fabric (495 g/m^2) and a double-layer suit made from Nomex III (2 times 265 g/m^2) of antistatic properties[8]. The flame-resistant suit is nowadays also worn as the normal working outfit of rescue team members (Fig.9). When explosion hazards prevail, protective hoods and gloves are worn as well.

7. Filter Self-Rescuer and Self-Contained Self-Rescuer

Ever since the filter self-rescuers were introduced in the German hardcoal industry during the fifties some 7 000 of these devices were used in about 560 escape events. Carrying a filter self-rescuer along is compulsory for the underground miner. Any and all filter self-rescuers used in the German coal industry cover the maximum admissible escape duration of 90 minutes[9,10].

The members of rescue teams will carry their personal filter self-rescuers, too. It is only during their work with donned breathing apparatus that the filter self-rescuer may be kept for them at the fresh-air base.

When starting out for a rescueing action every squad takes along at least one self-contained self-rescuer; for inert atmosperes the squad members even take a number of them along or have them kept ready, easily visible, within their work area. When miners have to be rescued the self-contained self-rescuer lends itself also to salvaging actions as far as the injured persons are still capable of breathing by their own. Mine rescue teams have been equipped for many years now with the Dräger Oxy-SR 45 type of self-contained units.

In 1982 German coalmine operators purchased 350 oxygen self-rescuers plus 450 spare oxygen units to test the chemical oxygen self-rescuer of Auer SSR 120 type (category K 90) [11]. The minimum operational time of this device is 90 minutes - even under escape and

working conditions of the rescue squad (its tidal volume is 35 l/min). In 60 underground and surface exercises 250 devices were donned over their entire operational time (Fig. 10). An average operational time of 120 minutes for underground escape exercises was attained by using 175 units.

In addition some 100 units were stored on different machines and vehicles, in escape boothes and on shelves, ready to be taken along. The purpose is to assess the influence of underground storage on the ageing behaviour of the units (Fig. 11).

These trials prompted several improvements of the apparatus design. It has been considered to use chemical oxygen self-rescuers - in addition to the basic filter-self-rescuers - also in the following areas besides mine rescue activities:

- in unusually long auxiliary-ventilated roadways;
- in auxiliary-ventilated roadways where Diesel-powered rubber-tyred vehicles are used, and
- in workings prone to gas eruptions[12].

8. Manual Measuring Devices

Gas measuring techniques have gained increasing importance for the work of rescue teams. Exclusively those types of manual and portable measuring instruments are in use besides manual oxygen measuring devices whose indications remain unaffected by lack of oxygen or whose cross sensitivity is easy to assess (Fig. 12). A major aspect is their non-interference with ongoing inertization operations. For first explorative actions the rescue squad should be equipped with fast indicating CO measuring devices as they yield measuring results much faster than the conventional tube-type units[13].

9. Equipment for a First Emergency Intervention

A good starting position for rapid first interventions has been created by keeping the equipment of the rescue teams ready in easily transportable dragging baskets at the mine rescue station (Fig. 13). This basic equipment is only for first exploration and will be supplemented whenever firefighting or rescueing of men is necessary. Back up material which is kept ready for easy transportation to the fresh-air base will be brought underground only, when further teams are starting out for action.

10. Fresh-Air Base

During the first intervention of the mine rescue team a stand-by group stays behind at a "temporary fresh-air base" being in telephone communication with the emergency management. As soon as possible upon consultation with the emergency management, one or more fresh-air bases will be installed (Fig. 14). On one hand, a fresh-air base should be as near as possible to the site of intervention, on the other hand, it should be at a safe distance from it. The overman supervises the fresh-air base. He reports directly to the emergency management[14]. The first intervention normally serves for exploration and, thus, falls under the concept of "aggravated conditions". Those underground workings fall into this category where humid and warm air, severely reduced visiblility, and sections with difficult travelling conditions prevail. Under these circumstances the members of stand-by groups, with oxygen breathing devices worn on their backs, stay as close to the site of intervention as possible without using the apparatus. This means that normally each fresh-air base is manned by three rescue groups.

11. Telephone Systems for Rescue Squads

Efficient information and communication between the advancing group and the fresh-air base is of critical importance for the safety of a rescue team. Here, intrinsically safe, sound-powered telephone

systems proved their usefulness. Language communication is amplified in both directions by using a loudspeaker. The stand-by group, thus, gets detailed information on its duties ahead. For first interventions the advancing group carries one or more line cartridges (weighing 2.6 kg) of 400 m length each which are fastened to the belt and unroll automatically (system No. I). After the first intervention this delicate thin line will be replaced by a more robust flat-strand line equipped with interception pinches (system No. II) (Fig. 15). Using these pinches the rescue group is able to "tap" the telephone line at any point between the site of intervention and the fresh-air base[15]. In some rescue actions where visibility was severely reduced, the telephone line was really a kind of Ariadne's thread and helped the rescue group to get out again.

Trials of radio sets for language communication indicate that such systems may also be of use for some aspects of mine rescue actions. For shaft interventions they have already turned out to be indispensable. The appertaining auditive and language quality has been markedly improved by adapters both for the telephone mask and for the winding cage set.

12. Physical Perseverance

Modern life style and the obsoleteness of physically exerting labour have resulted in a general restriction of physical mobility. This, in turn, leads to a reduced capacity of physical perseverance. We observed that rescue team members during their work - and specifically when travelling through inclined workings - as well as during their exercises showed increasing signs of physical deficiency.

In 1978 we, therefore, determined the perseverance characteristics of 300 rescue team members by subjecting them to exercises on the ergometer bicycle. An inadequately trained physical condition was

observed with 14% of the men![16] Only 42% of the persons examined showed good or even excellent physical perseverance (Fig. 16). In an emergency situation the physical deficiencies stated will not only endanger the individual in question but also the other group members. We, therefore, introduced four remedial measures:

- Examinations by the services of occupational medicine

  The regular ergometric examinations in the framework of check-ups by the services of occupational medicine are now carried out by subjecting the men to maximum loads depending on their age and weight, i.e. the desirable heart frequency should be 200, minus age (Fig. 17). Here, a physical performance should be achieved equalling three times the weight[17]. If training is inadequate, the persons are offered a purposeful perseverance training.

- Exercises at surface facilities, including perseverance exercises

  The two hours of surface exercises were completed by a "perseverance" section which is focussed on the aspects force training, travelling, working, and which includes a perseverance training of 15 minutes. The bicycles are used for perseverance training. The load, starting with 1.2 W times kg of body weight, is increased by two increments of 20 W each (sub-maximum load).

- Checking of physical condition

  The same ergometer bicycle is used for checking the physical condition of the men, with monitoring of pulse frequency. The result is displayed as a characteristic value and plotted on a perseverance chart (Fig. 18). This checking is also done at sub-maximum load. If a person shows physical deficiencies the overman will, as the case may be, have him examined by the services of occupational medicine.

- Training

There are several kinds of activities apt to build up and maintain physical endurance. For this purpose we established training suggestions containing practical instructions as to the frequency, intensitiy and duration to be observed. Running exercises are especially promoted by long-distance running competitions over 10 and 17 km in which so far up to 750 rescue team members attended at one time. Training locations equipped with isokinetic training devices were installed at two different sites.

13. Manriding Facilities

When doing exercises in inclined drifts it became obvious that rescue men, even in a perfect physical condition, connot do without mechanical manriding facilities (Fig.19). All technical and organizational potentials should, therefore, be utilized to make manriding facilities in good working order available also in cases of mine fires or explosions. In several instances operator stands or drives were either transferred to the intake air side or designed in a way that they can continue operating also in emergency situations, (e.g. by pressure ventilation). In long roadways with auxiliary ventilation rail bicycles are kept ready either for escape purposes or for advancing rescue groups [18].

14. Duration of Rescue Actions in Humid and Warm Mine Air

Due to aggravated climate conditions the normal duration of a mine rescue action often exceeds the individual intervention time. This applies, in particular, to the extinction of open and incipient mine fires - especially if the cooling systems break down - as well as to travelling in isolated workings. At temperatures of for example $t_d = 36^\circ$ C and $t_w = 32^\circ$ C the intervention is reduced to one hour (Fig.20). Then four groups are required to permanently man the site. If temperatures reach $t_d = 43^\circ$ C and $t_w = 38^\circ$ C, the action has to be

reduced to as little as 20 minutes. In this case one even needs nine groups if gaps are to be avoided. Presently comprehensive investigations are pursued in a climate test plant set up at the mine rescue center. It serves for checking the figures contained in the table as well as for determining the influence of various types of clothing and physical strain. Besides cooling waistcoats, a combined cooling and breathing apparatus is also tested (Fig. 21). For ease of comparison between various pieces of clothing the so-called "Wet-Dry Index" (WD-Index) is used. It is calculated from dry bulb and wet bulb temperatures as follows:

$$WD = 0{,}85 \times t_w + 0{,}15 \times t_d \quad (19)$$

The investigation results indicate that the previous maximum admissible intervention times can be protracted or that intervention at high WD numbers will become possible at all by using cooling garments in humid and warm mine air [20].

Since 1983 the indoors exercises at the mine rescue center in Essen include a 10 minutes exercise at $t_d = 40^\circ$ C and $t_w = 31^\circ$C ($\hat{=}$ 50% humidity of the room air). Due to the aggravated physical strain we were obliged to shorten the duration of that exercise from initially 120 minutes to 100 minutes. In addition, there is a facility for special "hot" exercises of alternatively 50, 30, and 20 minutes duration.

15. Spotlights of Fire Protection

Massive endeavours to improve fire protection have contributed to an almost zero rate of bigger open mine fires during the recent years. Timber consumption in mines has been decreasing from 21 solid cubicmeters in 1960 to presently 5 solid cubicmeters per 1 000 tons of saleable output. Most of the timber brought underground will first be impregnated by flame-inhibiting salt solutions.

Inflammable hydraulic fluids were substituted by flame-resistant ones although, quite recently, a certain category of flame-resistant hydraulic fluids (HFD) - due to their high content of polychlorated biphenols - had to be replaced by newly developed fluids.

Fire protection equipment of rubber-tyred Diesel vehicles seems to require further improvement.

The transformation to self-extinguishing conveyor belt fabrics which started in 1975, was completed in 1981, whereas steel-layered belts having similar properties had conquered about 62% of that sector by late in 1983.

Premature warning of the underground workforce is ensured by a dense network of more than 1 200 CO recorders and communication systems. 21 mines use processors for premature identification of mine fires.

Roadside stoppings are a standard feature of any modern face area. In many instances they have proved their usefulness as a prerequisite for effective suppression of spontaneous combustion in the goaf. Both hopper-type and vertical transport systems installed on the surface have increasingly been used for bringing the appertaining construction material down into the mine. The systems offer obvious advantages as far as guniting, lagging and construction of stoppings is concerned. The consumption of powdered and granular construction material has arrived at about 1.5 million t/year which is three times as much as in 1977[21].

16. Spotlights of Firefighting

An efficient network of water mains is still considered to be the best means for fighting developing fires. Ideally at any point of the mine a water flow of at least 400 l/min at a flow pressure greater than 1.5 bar can be tapped. Massive precautions for firefighting were taken in roadways with means of belt conveyance, i.e.[22]:

- 3/4" extinction water valves every 25 m;
- hoses and spray lances every 150 m (in inclined roadways greater than 10 degrees dip every 50 m);
- 2" extinction water connections at drive motors, return points and roadway branchings;
- self-triggered water extinguishing devices at drives and return points.

Some 900 km of belt installations were protected in this manner, using about 3 500 extinction units. Some 300 storage-rooms, maintenance workshops, and service stations for Diesel vehicles are protected in a similar way. In this case the water feed amounts to at least 10 l/m^2. The Diesel vehicles are equipped with HRD powder extinction devices. Other self-triggering water extinction devices have been installed in roadways and staple shafts containing inflammable support elements and shaft inserts. They are meant to limit the propagation of a fire and prevent secondary fires.

Extinction powder proved to be another excellent means of fire extinction. The 30 mines of the Ruhr coalfield have made 30 000 manual fire extinguishers available at hazard points containing 10 kg powder each.

In roadway headings with stronger than normal gas emissions 50 kg powder extinguishers with long hoses are mounted to boom roadheaders. Tunneling machines have been equipped with HRD powder extinguishing systems (Fig. 22). Due to the hazard of reignitions during the extinction of methane fires, additional pressurized lances are kept in stand-by[23,24].

The personnel of such mines is thoroughly trained - both theoretically and practically - in handling these extinction devices. At times the men are explicitely told that any changes of the ventilation system may be done exclusively upon consultation with the emergency management. In 1983 the men working in boom miner heading developments had, in three different instances (Lorraine, Ruhr, Saar)

interrupted the auxiliary fan after vain attempts to get the fire under control. Unfortunately, this created a particular explosion hazard for the personnel working in neighbouring areas and also for the mine rescue squad approaching the accident site. In two incidents this hazard could be counteracted only by nitrogen inertization.

When isolating mine fires, the mine air flow shall as long as possible be maintained until closing of the stoppings, in order to cope with possible explosion hazards. For this purpose one or two parallel pipe systems (Ø 700 mm) are built into the stopping. The pipe hoods are as explosion-proof as the stoppings themselves (>5 bar). By incorporating two pipe traps a very simple sluice system is created (Fig. 23).

Notwithstanding a number of manual and stationary measuring instruments monitoring specific or several gases, gas sampling and precise analysis cannot be done without in case of a mine fire. The results of this form, indeed, a basis for evaluating the explosion risk prevailing, the fire behaviour to be expected (volume and intensity) and the firefighting measures to be taken[25].

An intrinsically safe underground laboratory as developed at Bergbau-Forschung determines all the gases entering the evaluation (CH_4, CO, H_2, CO_2, O_2) at almost analytic accuracy. The measuring data are transmitted to the surface and evaluated in the computer (Fig. 24). This allows faster decision-making by emergency management than previously[26].

17. Firefighting by Means of Nitrogen

It was in December 1974 when for the first time in West German hardcoal mining liquid nitrogen was evaporated at the surface and introduced, at a rate of approximately 60 m^3/min, to an underground fire zone. Inertization was developed into a standard procedure of mine firefighting, which was applied in 63 emergencies through 1983 (Fig. 25). With a nitrogen consumption of some 207 million m^3 50 face equipments plus a daily output volume of approximately 60 000 t

were saved. Thanks to steady progress in technology, organization, and logistics it is possible, nowadays, to apply the procedure anywhere in our coalfield within less than twelve hours[27, 28].

The objective of mine fire inertization is to reduce the oxygen content of the mine air and thus avoid explosion hazards as well as to restrict the fire extension and intensity. To make a methane/air mix inexplosible its oxygen content has to be decreased to less than 12% by volume. This is also sufficient to extinguish an open flame fire. To fight spontaneous combustion fires and other incipient fires successfully, the oxygen content has to be diluted to less than 3%. Moreover, for interventions in warm underground pits the supply of cold and dry nitrogen alleviates the working conditions for rescue men. And, in particular cases, explosible methane/air mixes can be safely flushed out by nitrogen.

For inertization of a fire zone one starts by filling a zone with nitrogen which has been isolated at least on the intake side (Fig. 26). The procedure is applied predominantly for fighting open fires or, in case of deep-seated fires, for eliminating explosion hazards in the caving area.

For object inertization the seat of a fire in the goaf is directly flooded with nitrogen (Fig. 27). This serves to replace the stray ventilation current supporting a deep-seated fire as completely as possible by inert gas. The nitrogen volume flow requirement will normally be lower than for inertization of a fire zone[29].

A deep-seated fire will almost never be definitely extinguished by the introduction of nitrogen. Thus conventional sealing is still necessary as additional precaution measure. Even with an open mine fire direct firefighting and cooling will have to be applied starting already during the inertization procedure.

Inertization has invalidated the previously clear distinction between sealing-off and reopening of fire zones. Nowadays there is a gradual transition between the two phases. Time-saving may be of vital importance to a mine when an underground area is to be recovered.

18. Typical Examples of Inertization

Figure 28 gives nine typical examples of inertization from the German mining industry. The first three of them have to do with spontaneous combustion fires in the goaf of longwall faces under extraction.

Case No. 4 is a big open mine fire in an inclined belt-conveying roadway with upcast ventilation.

Cases 5 and 6 relate to mechanized roadheading operations which had to be abandoned temporarily due to methane ingnitions.

Cases 7 and 8 illustrate the technique of flushing roadways by nitrogen; in case 7 nitrogen is introduced to improve climate conditions and in case 8 for counteracting the explosion hazard.

The last case refers to a methane fire during shaft-sinking operations which was successfully extinguished by flooding. The original plan was to use CO_2 as extinguishing agent in order to prevent damages to the electrics of the shaft-sinking equipment.

When dealing more closely with these typical examples, it becomes obvious that there is still a good potential of advancing the strategy of mine firefighting by means of inert gases[30].

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Fig. 1

1984	Coal-measures in the Federal Republic of Germany	HGRWE

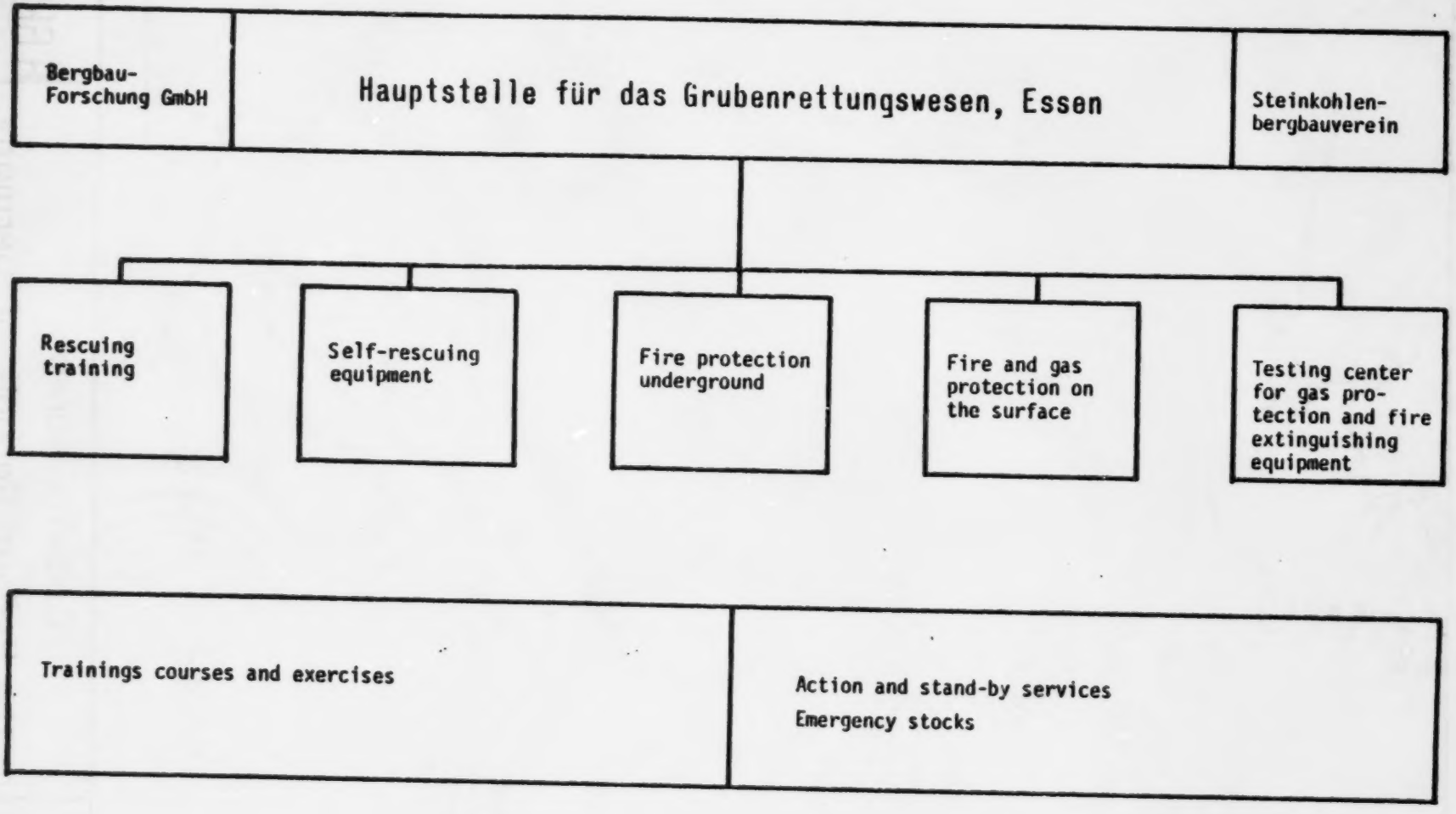
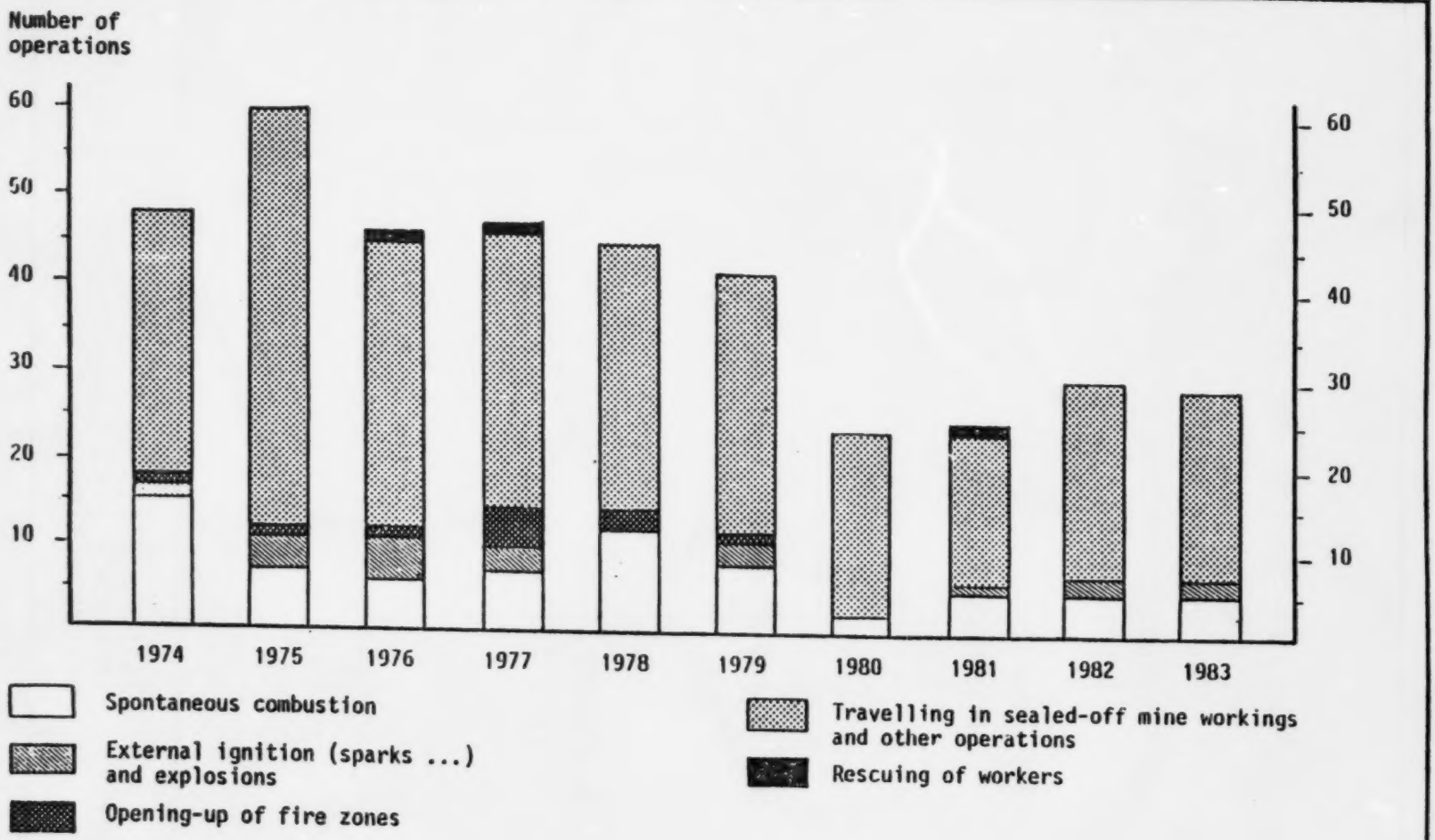


Fig. 2

1984	Organizational structure of the "Hauptstelle für das Grubenrettungswesen", Essen	H GRW E



1984 | Number of mine rescue operations (1974 - 1983) | HGRWE

Fig. 3

Fig. 4

1. Measures required for safeguarding men, e.g. evacuation and isolation of ventilation sections, instruction on escape ways and request to don self-rescuers.

2. Preventing outsiders from going underground.

3. Getting the first rescue team started.

4. Having the main ventilator and the winding engine taken over.

5. Prevention of changes in the ventilation system.

1984	Responsibilities of the temporary leader of a rescue action	H GRW E

A. Safety for personnel

1. Evacuation and barring of hazardous areas.
2. Instructions to rescue emergency victims.
3. Arrangements for underground transport of emergency victims.
4. Order to man the winding machine.
5. Registration of persons coming out from underground, interdiction of descent to unauthorized personnel.
6. Spotting of each individual of the staff concerned.
7. Interrogation of supervisory personnel and staff as to the situation underground.
8. Arrangements for transfer to hospital in case of suspected CO-poisoning.

1984	Tasks of the emergency management group	H GRW E

B. Control of rescue squad action

1. Missions assigned to squads as per mine rescue procedures.
2. Assignment and definition of tasks of squad leaders.
3. Consideration given to climatic conditions.
4. Avoid advances against air streams from mine fires if possible.
5. In case of open mine fire, respiratory apparatuses are to be used even when advancing with the air stream.
6. Start firefighting from luff of the ventilation air stream.
7. Beware of roof fall in burned-out workings.
8. In vertical mine workings secure against fall.
9. Appoint surface liaison officers for the mine rescue squads.

1984	Tasks of the emergency management group	H GRW E

C. MINE VENTILATION-RELATED PROCEDURES

1. Check ventilation of the mine workings concerned; carry out check measurements.
2. Watch CO development; poll measured values by the colliery control center in regular intervals.
3. In case of hidden mine fires, check CO release by manual measurements.
4. Man the main fans.
5. Watch main fan in the return of hot mine fire gases.
6. Adjust the main fan only after agreement with the ventilation engineer.
7. Do not stop auxiliary ventilation units, do not restart either, if not absolutely necessary.
8. Check methane drainage, if possible do not shut down.
9. Take gas samples for monitoring ventilation air.
10. Alert central laboratory, possibly send mobile and underground laboratory to colliery.
11. Arrange for transport of gas sampling tubes.
12. Assess analyses in view of fire development and explosion risks.
13. Always check fire gas samples also for H_2.

1984	Tasks of the emergency management group	H GRW E

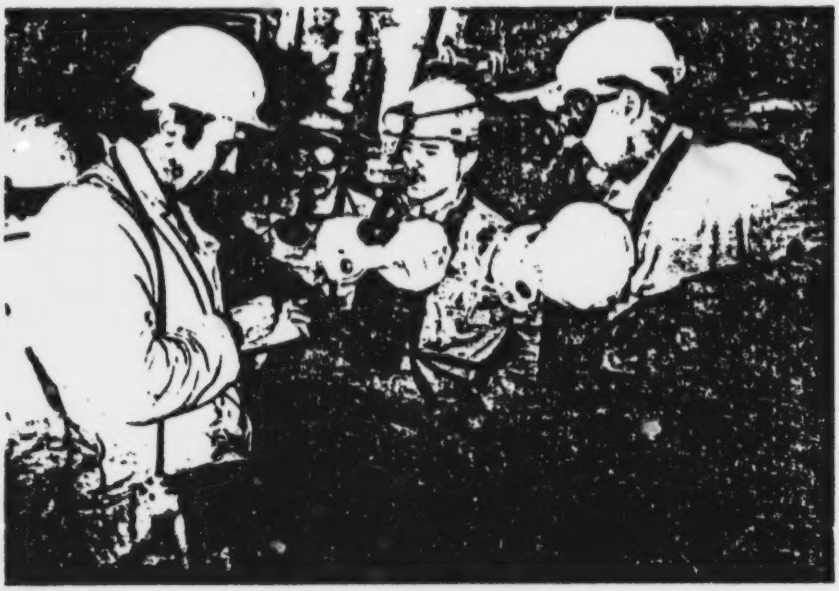
D. FIRE FIGHTING

1. Start firefighting from the intake site as soon as possible.
2. Specify measures to be taken.
3. Spot possible secondary points of ignition.
4. Take preventive action against propagation of fire and of secondary ignition.
5. If necessary release fire fighting systems in the shafts, watch ventilation.
6. Decide on places and methods of stoppings.
7. In areas of explosion risks take precausionary actions for construction of stoppings.
8. Start measures for inertizing.
9. Place inertizing equipment.
10. Assure sufficient nitrogen supply.
11. Lay out fire hoses, if necessary integrate pipelines into the firefighting network.
12. Check inert gas lines for leaks.
13. Watch special risks for mine rescue squads in inert atmosphere.

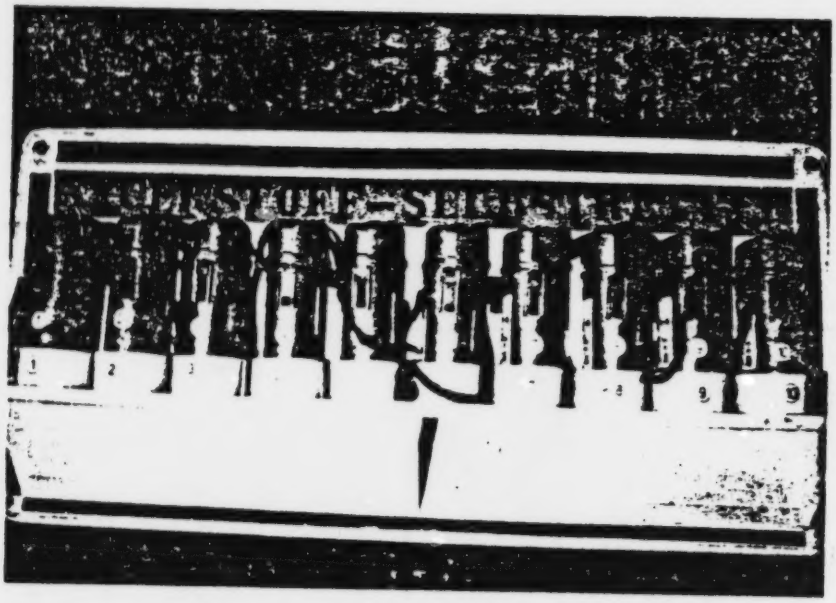
1984	Tasks of the emergency management group	H GRW E

1984	Rescue squad with fire protecting suit (= standard dress)	H GRW E

Fig. 10



1984	Field testing of SCSR Auer SSR 120 (Klasse K 90) Chemical type	H GRW E



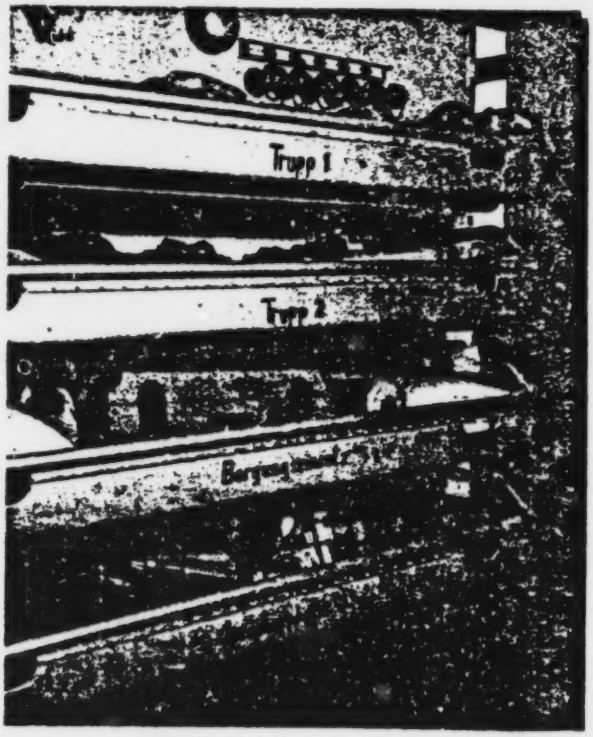
1984	Storage of SCSR Auer SSR 120 (Klasse K 90) underground	H GRW E

manufacturer type	application	measuring range	measuring principle
Auer M 502	manual methane measuring device	0 - 2 % / 0 - 5 % CH_4	heating tone
Auer M 510 B	manual methane measuring device	0 - 100 % CH_4	thermal conductance
Auer A 2 WT	portable explosimeter measuring device	0 - 100 % UEG	heating tone
Auer Oxygen-Indicator model "P"	manual oxygen measuring device	0 - 25 % O_2	electrochemical detector
Dräger COMOWARN	portable CO-measuring devices	0 - 100 ppm CO 0 - 200 ppm CO 0 - 400 ppm CO 0 -2000 ppm CO	electrochemical detector
gas detector tubes	Auer / Dräger CO, CO_2 and others	different measuring ranges	chemical reaction (changing colour)

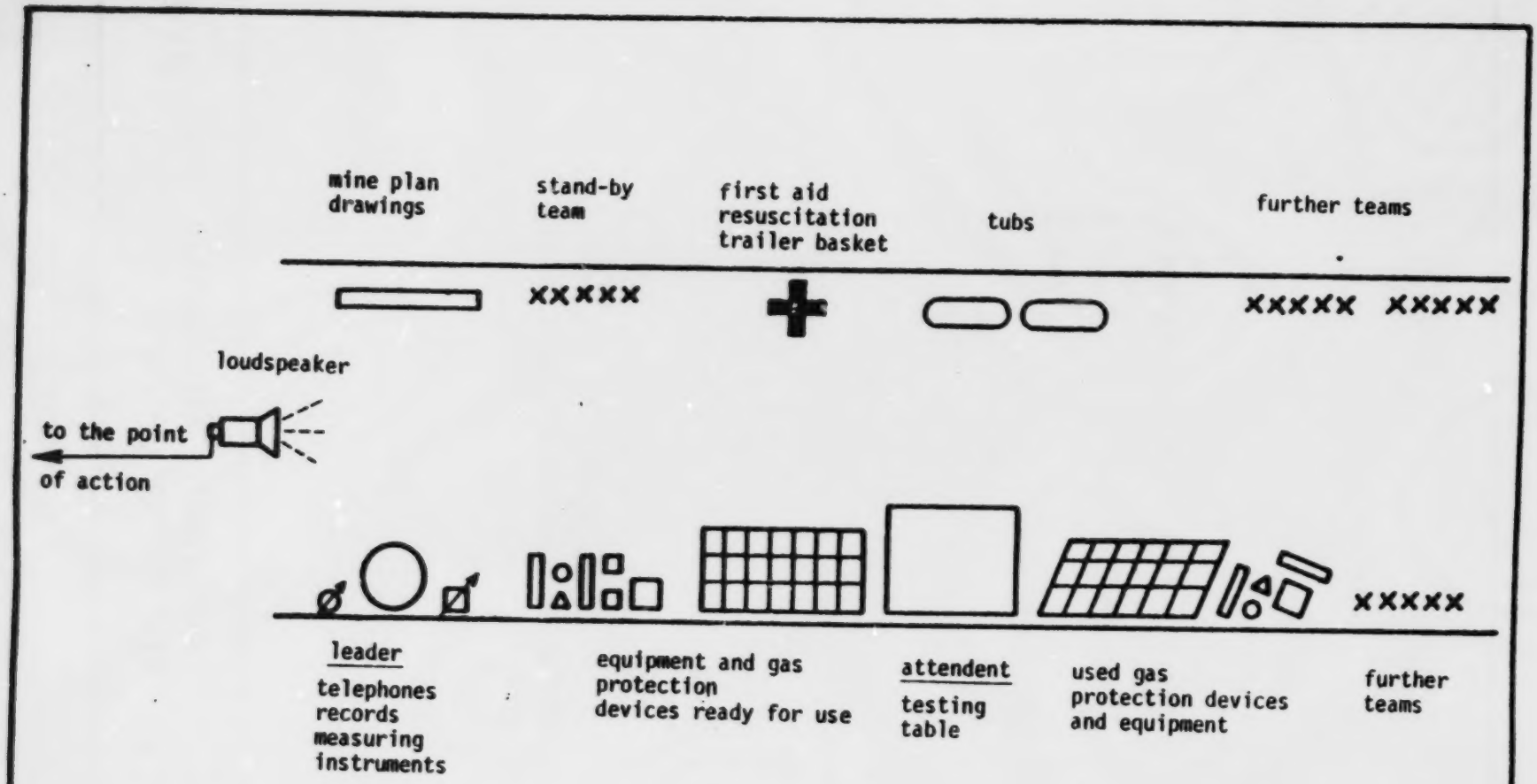
Fig. 12

1984	Manual measuring devices and portable measuring instruments	H GRW E

Fig. 13



1984	Equipment for first action by mine rescue teams	H GRW E

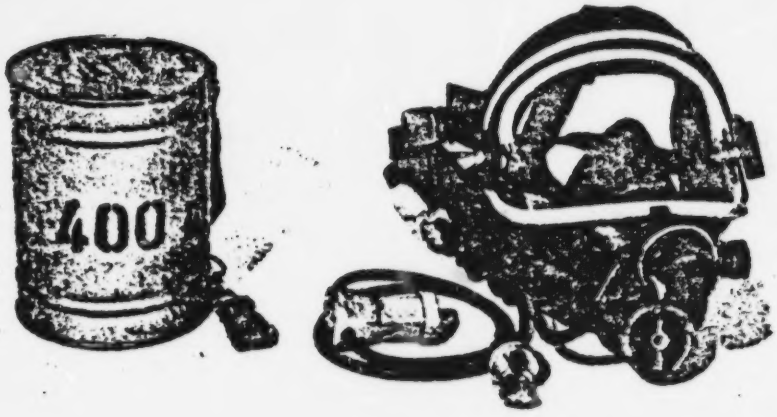


1984	Schematic organization of a fresh-air base	H GRW E

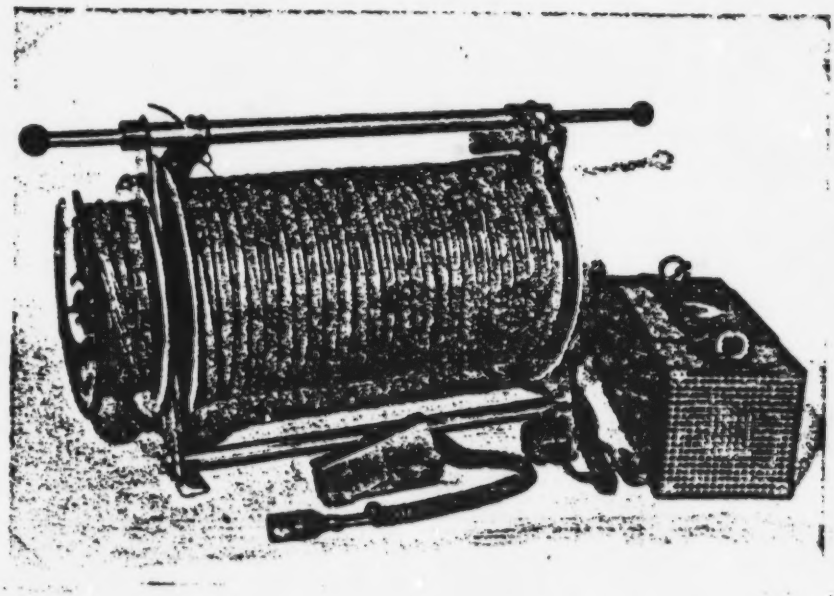
Fig. 14

Fig. 15

I



II

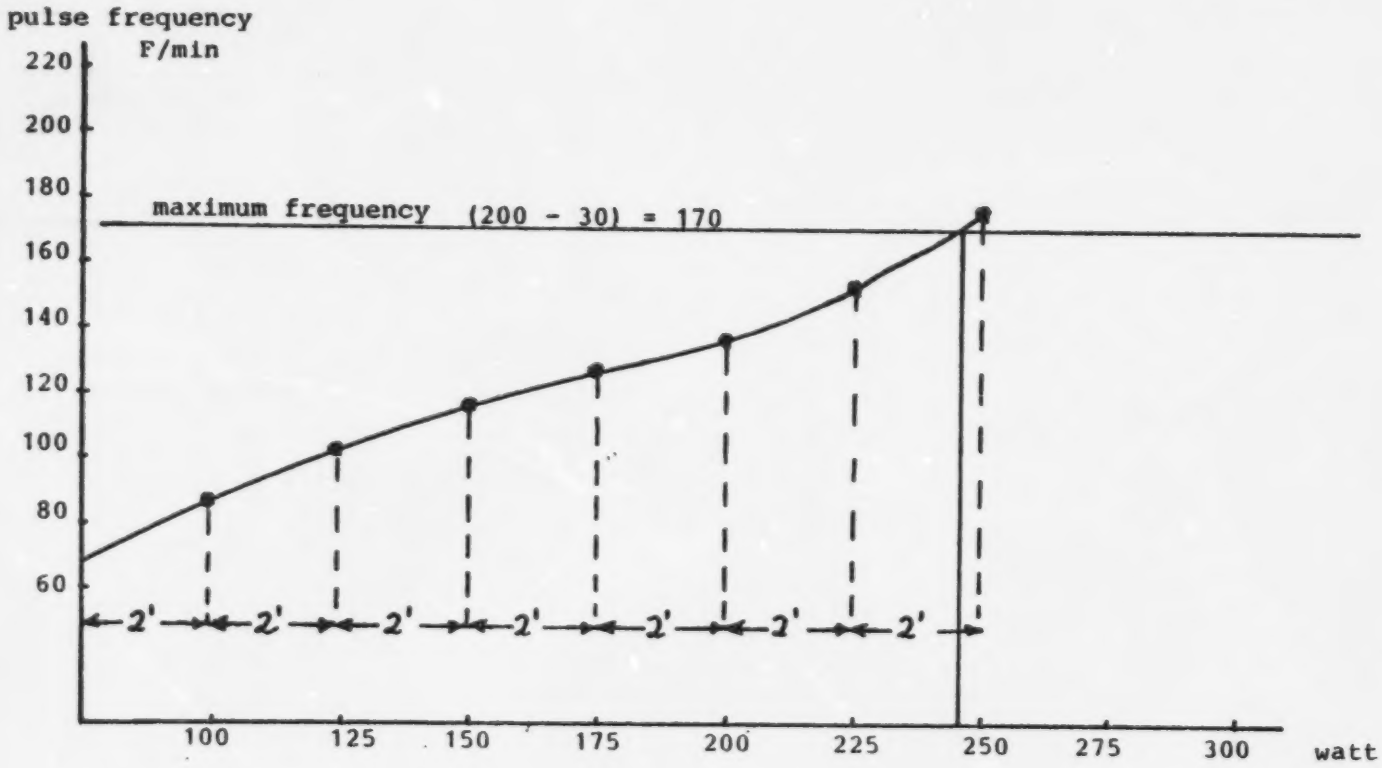


1984	Mine rescue telephone I and II	H GRW E

characteristic value	classification	percentage	
< 75	bad	14	58 %
76 - 100	moderate	44	
101 - 125	good	35	42 %
> 125	very good	7	

Fig. 16

1984	Characteristic perseverance values for 300 members of mine rescue teams (1978)	H GRW E



required: weight (kg) x 3 (watt/kg) minus 1 % per year of age above 30

in this case: 80 (kg) x 3 (watt/kg) = 240 watt

actual: 245 watt ≙ required value + 2 %

family name: M E I E R christian name: Hans age: 30 years weight: 80 kg

Fig. 17

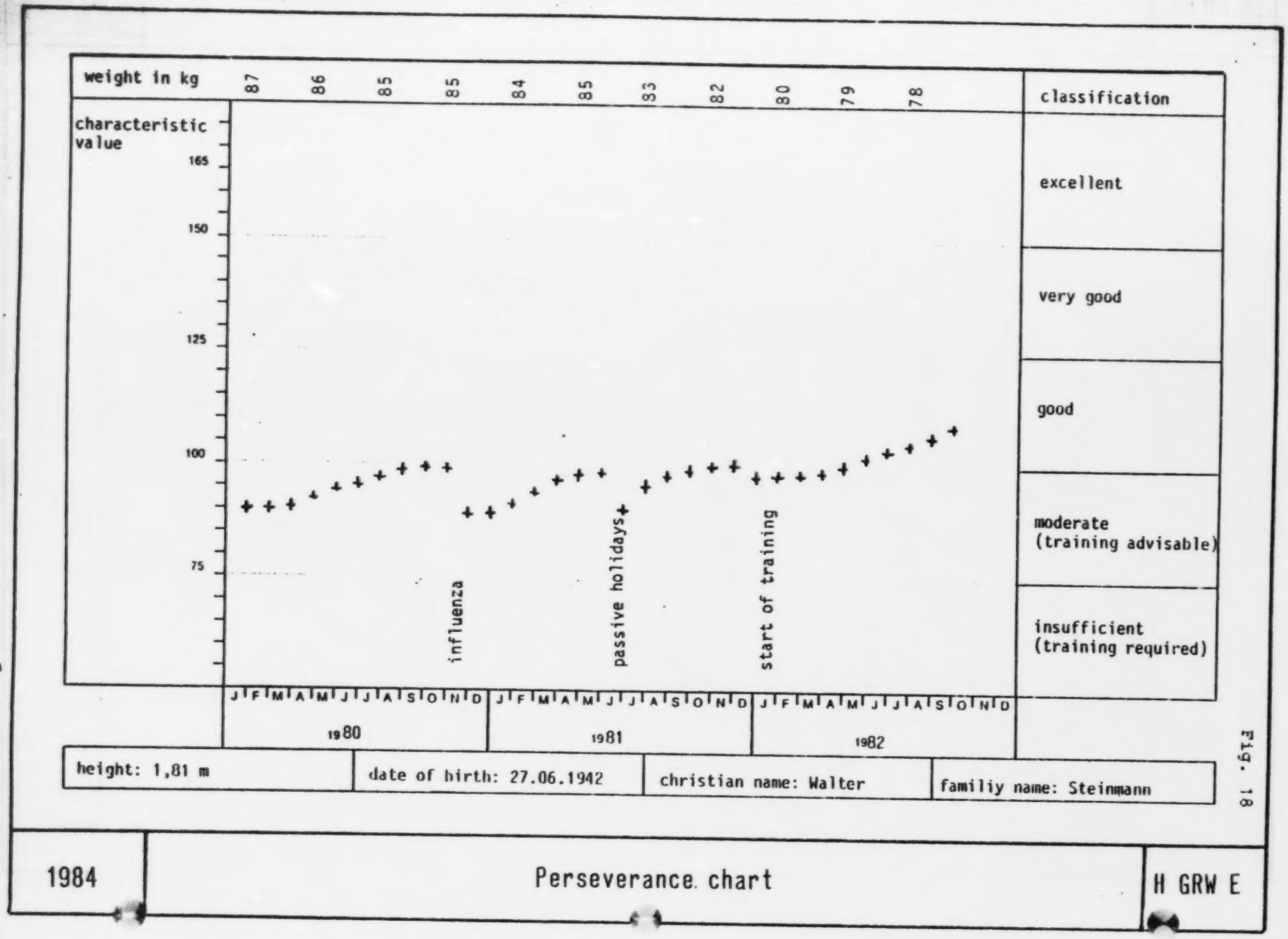


Fig. 18

1984 | Perseverance chart | H GRW E

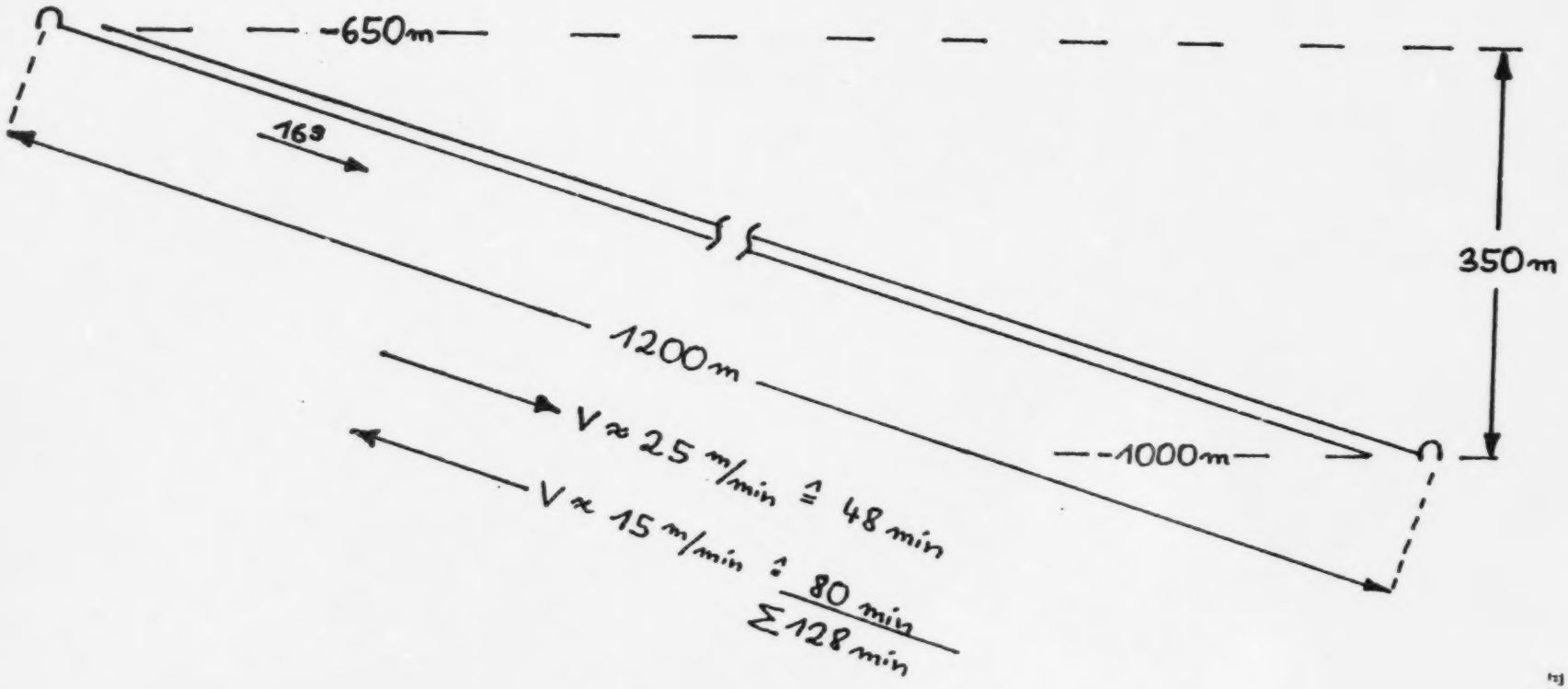


Fig. 19

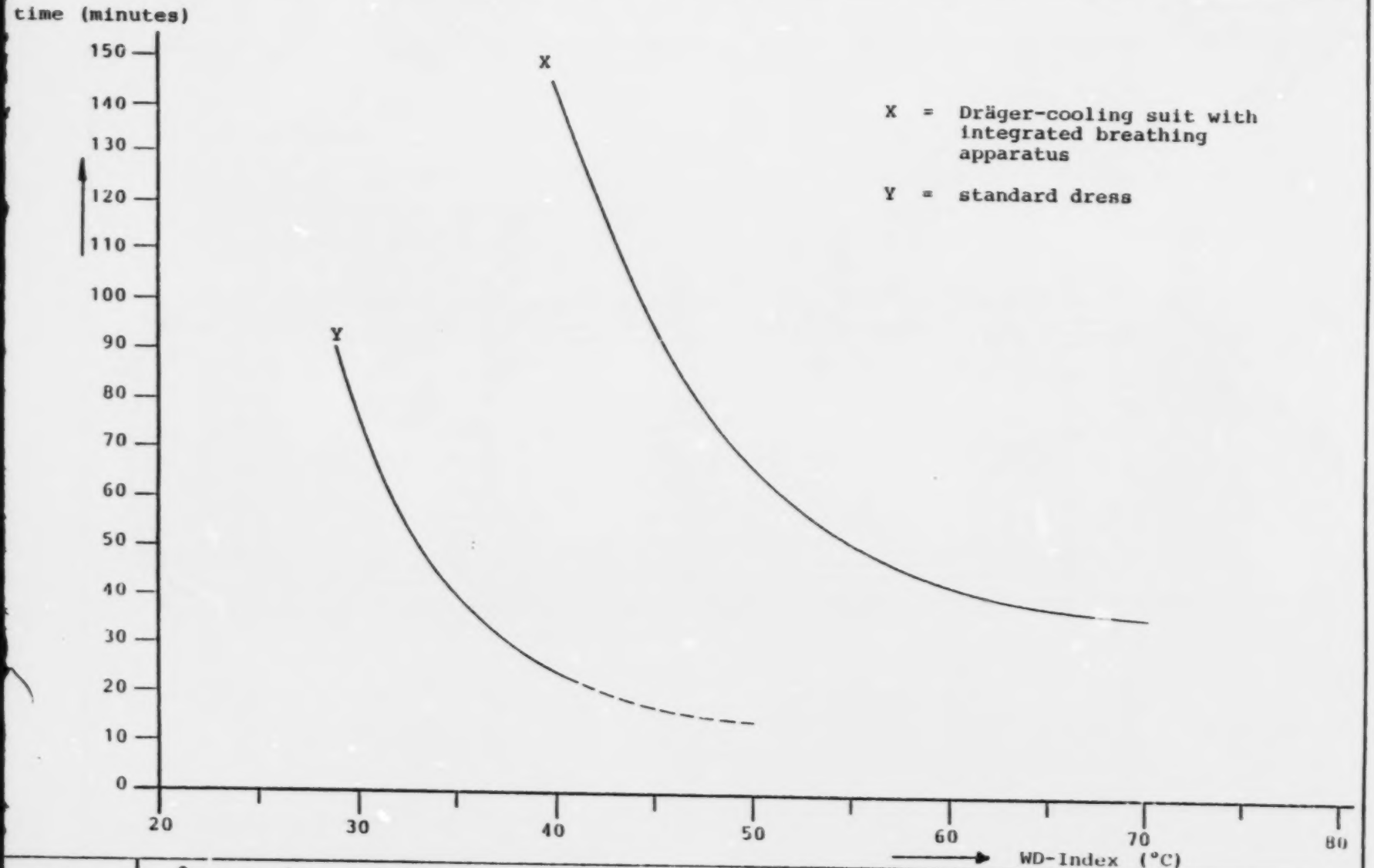
1984	Travelling in drifts by mine rescue teams	H GRW E

wet bulb temperature t_w [°C]	duration of action in minutes for Δt^* below 5 °C	for Δt^* 5 to 10 °C	for Δt^* above 10 °C
29	90	85	80
30	80	75	70
31	70	65	60
32	60	55	50
33	50	45	40
34	45	40	35
35	40	35	30
36	35	30	25
37	30	25	20
38 - 40	25	20	15

*Δt = difference between dry bulb temperature (t_{dl}) and wet bulb temperature (t_w)

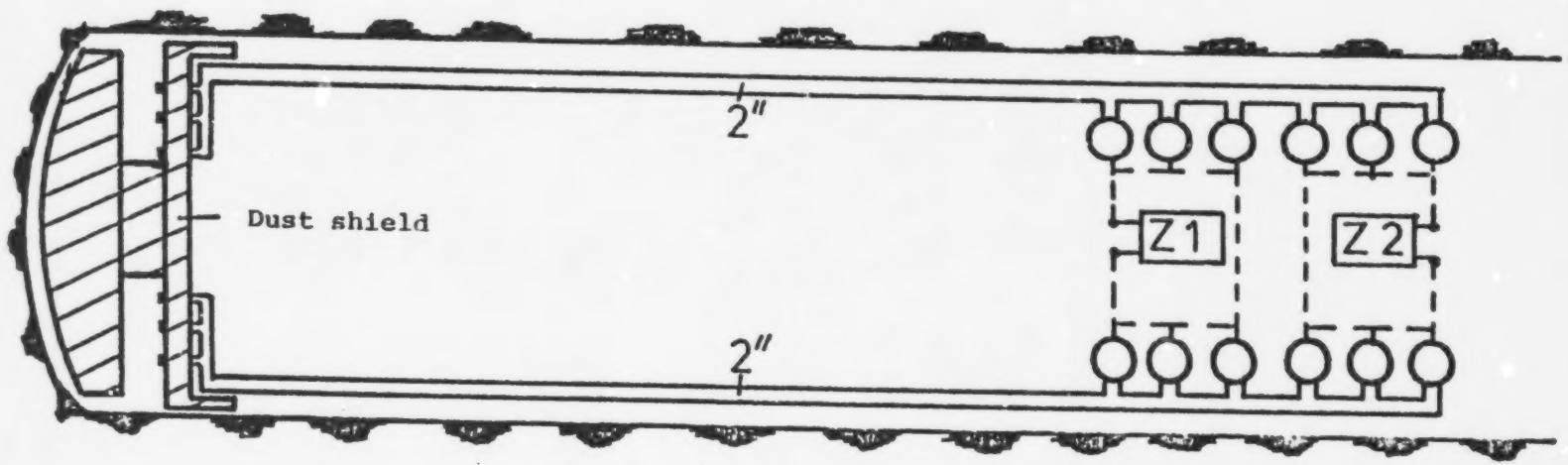
Fig. 20

1984	Duration of action by mine rescue teams in wet and warm air	H GRW E



1984	Comparative plot of possible durations of missions with and without cooling suit	H GRW E

Fig. 21



6 nozzles of 3/4" dia with
bust discs for pressure build-up

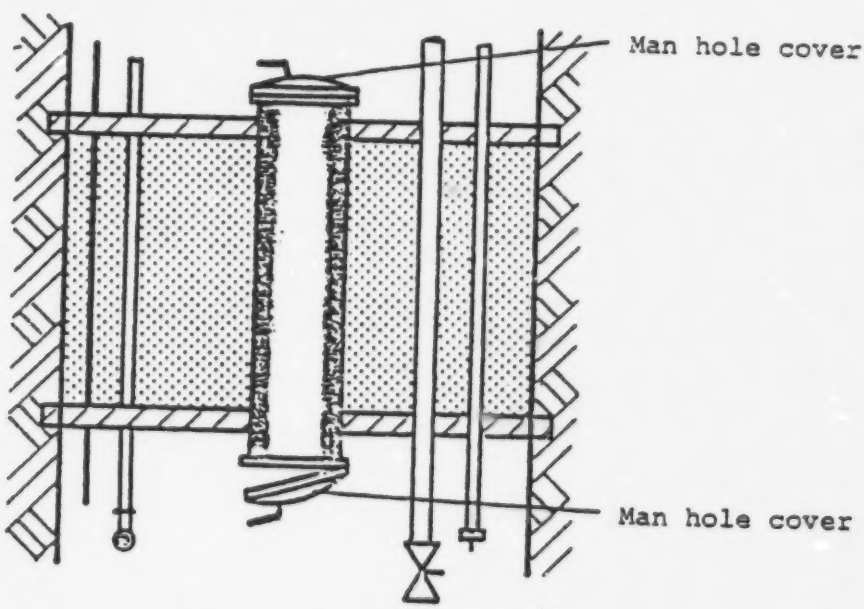
2 x 6 10 kg of extinguishing agents
Trigger units on the control panel

1984	HRD extinction unit (firefighting unit)	HGRWE

Fig. 22

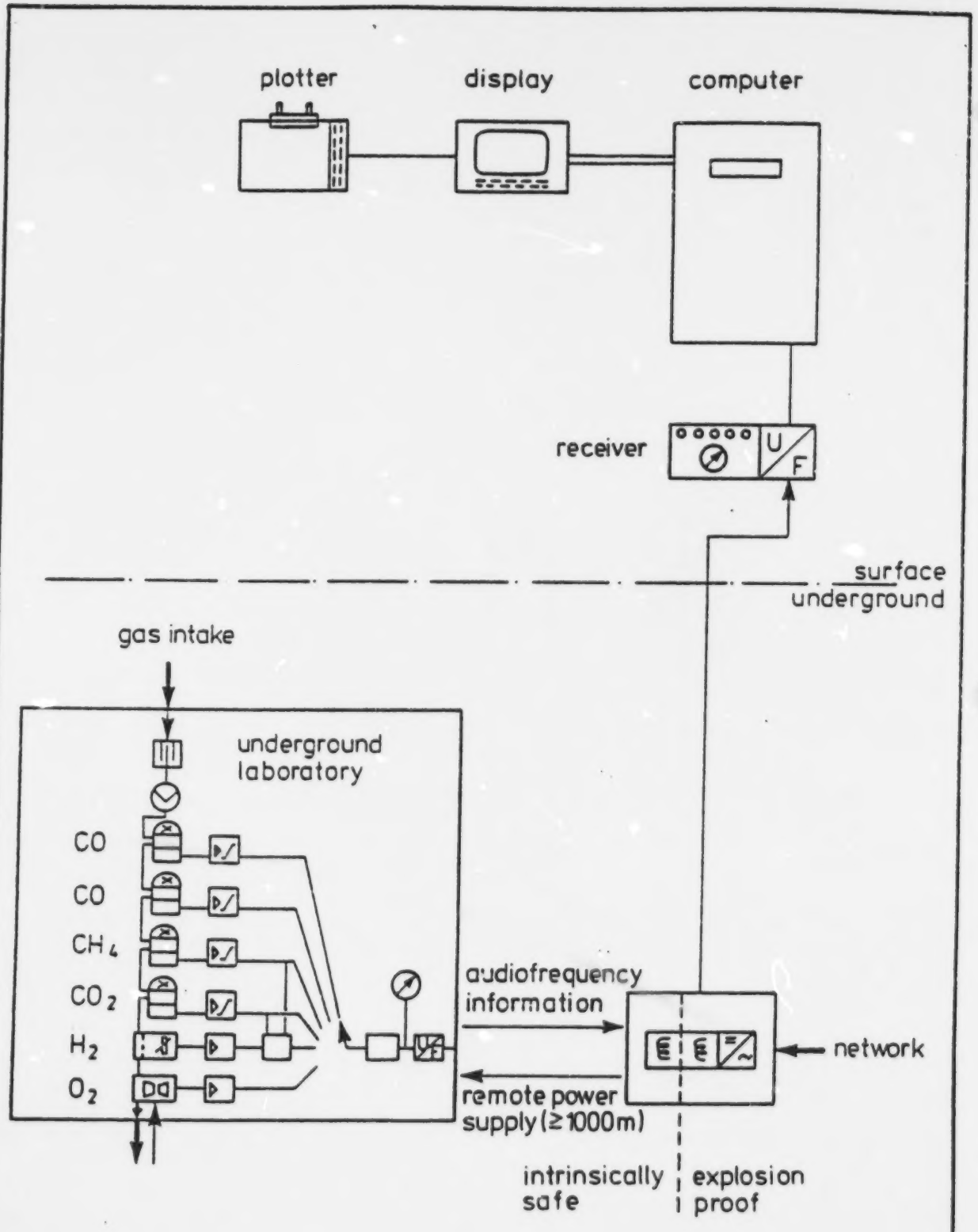
Fig. 23

"Inside"

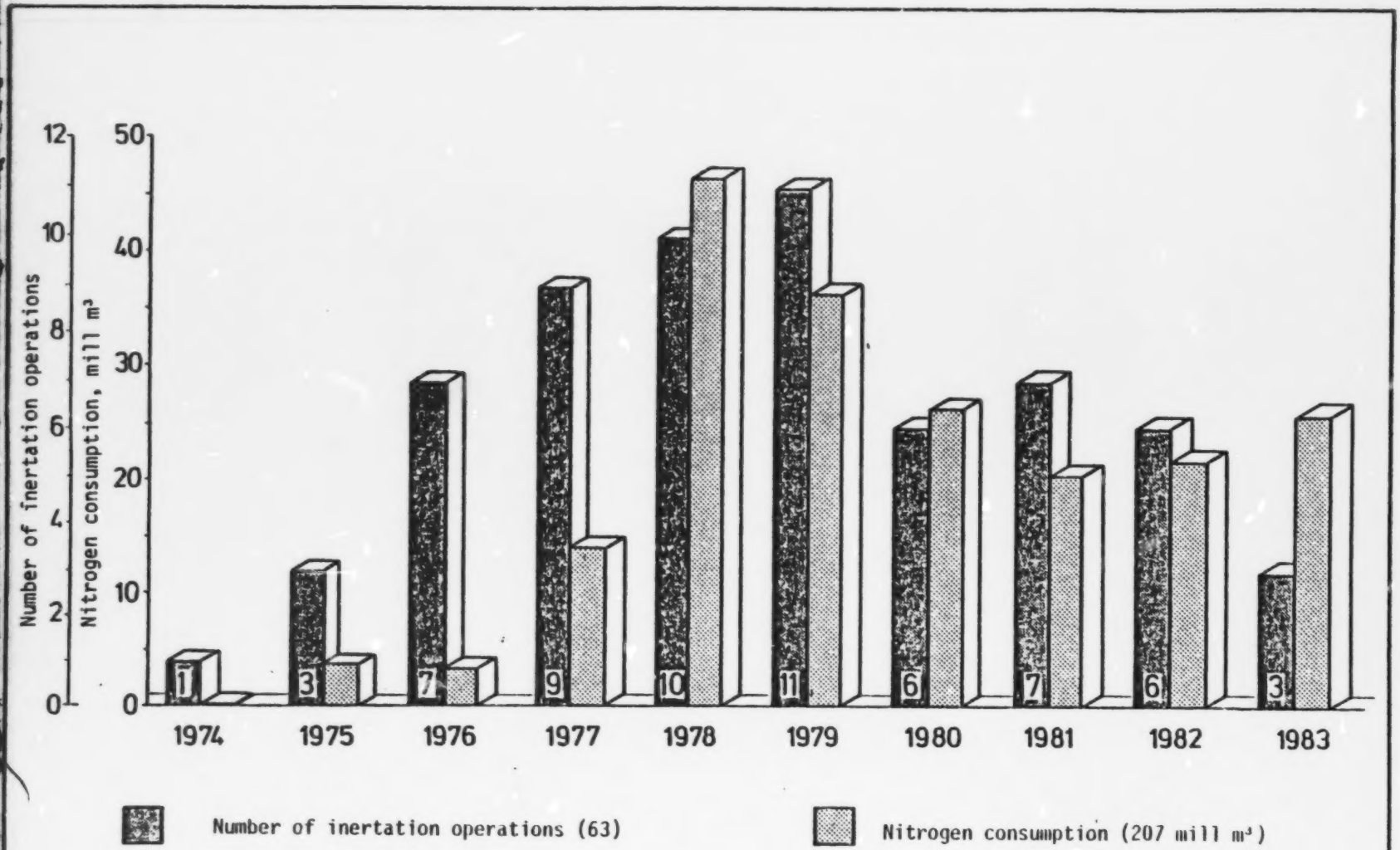


"Outside"

1984	Tubular lock system for stoppings	HGRWE



1984	Automatic Fire Gas Analyser	HGRW E



1984	Number of inertation operations and nitrogen consumption 1974 - 1983	HGRW E

Fig. 25

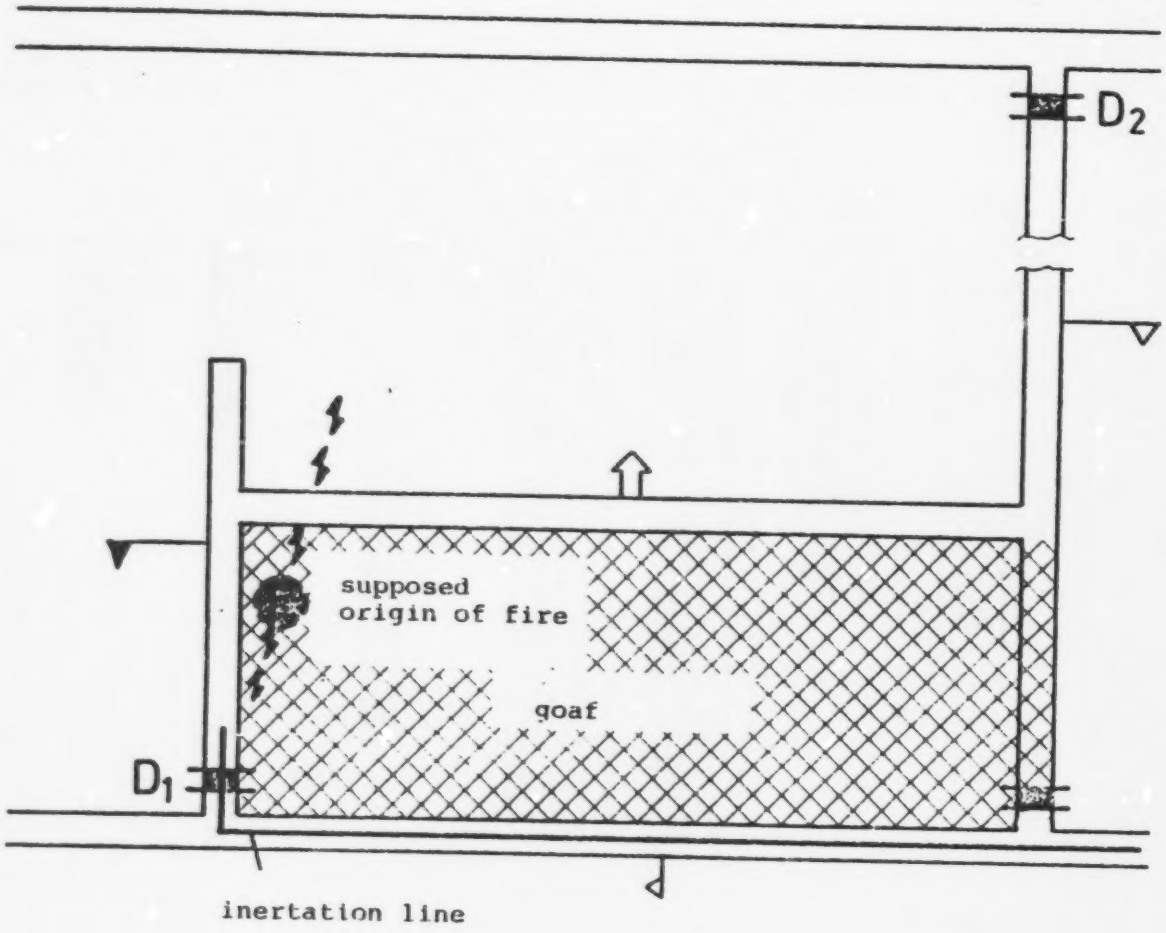


Fig. 26

1984	Sealing-off and inertation of workings	GRW E

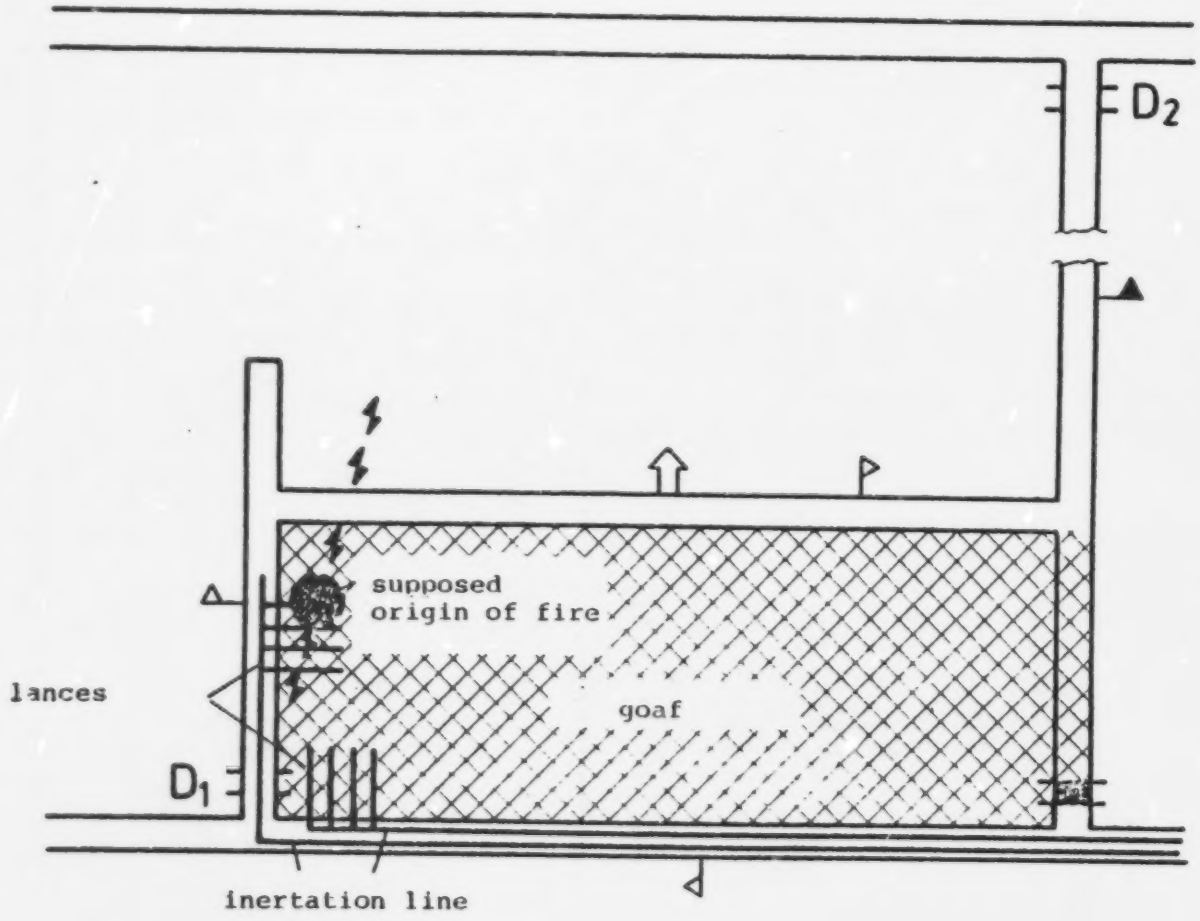


Fig. 27

1984	Inertation of objects	HGRW E

No.	Mine	Year	Event and location	Remarks	Duration (days)	Consumption (in million m³)	Volume flow (m³/min) max.	Volume flow (m³/min) ø
1	Osterfeld	1981	Spontaneous combustion in the goaf of an active mining area	Production and equipment saved	558	6,6	50	6
2	Radbod	1982	Spontaneous combustion in the goaf of a boundarynear mining area	Equipment saved	30	1,3	50	30
3	Rheinland	1982	Spontaneous combustion and methane ignition in the goaf of an active mining area	Restriction of the fire zone; production and equipment saved	58	18,6	300	64
4	Schlägel & Eisen	1977	Open mine fire in an inclined roadway with belt installation	Complete recovery of the fire zone	34	9,6	500	196
5	Westfalen	1982	Methane ignition during road-heading with a tunneling machine	Section-wise recovery of the roadway	9	1,5	270	115
6	Luisenthal	1983	Methane ignition during road-heading with a partphase roadheader	Recovery of the roadway	5	0,08	130	14
7	Heinrich Robert	1979	Spontaneous ignition in a roadway in course of withdrawal	Improvement of climate conditions during restriction of the fire zone	2	0,15	60	52
8	Hansa	1979	Explosion in a hydro-mined face	Subdueing of explosion hazards during flushing of the roadways	6	0,3	100	35
9	Haus Aden	1984	Methane ignition during shaft-sinking	Extinction by flooding; advantages of CO_2 inertization	5 h	0,001	4	3

1984 — Typical examples of inertization — H GRW E

Fig. 28

AR-72.2

UNDERGROUND MINE FIRE CONTROL

SECTION 4

FIRE COMBAT EXPERIENCE IN FRENCH UNDERGROUND MINES

by

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FIRE COMBAT EXPERIENCE IN FRENCH UNDERGROUND MINES

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1 - COAL MINING IN FRANCE

The production of coal in France comes from 3 coal basins :

- Nord Pas de Calais in the North of the country,
- Lorraine in the East,
- Centre Midi, which comprises several relatively scattered mines in the South East of France.

In 1983, French coal production was 18.5 Mt of cleaned saleable coal of which :

- 3.2 came from Nord Pas de Calais,
- 10.6 from Lorraine,
- 4.7 from Centre Midi.

The deposits mined by the different coal mines are most diversified in many respects :

- coal quality which varies from anthracites to bituminous coals and lignites,
- steepness of coal seams which varies from 0 to 90°,
- seam thickness varies from 0.7 to more than 10 m and in some cases massive coal accumulations,
- depth varies from zero in the case of open pit mines to 1 250 m maximum,
- methods of mining with/or without stowing,
- and finally susceptibility to self-heating, a characteristic which is inexistent in some deposits but can be very critical in others.

2 - THE CONVENTIONAL APPROACH FOR CONTROLLING SELF-HEATING COAL

In French collieries, all conventional methods of prevention against self-heating of coal are applied.

These conventional methods comprise of the following :

- identification of the most susceptible coal seams ; these are often known by long experience,

- determination of the conditions that are most favourable for the occurrence of self-heating of coal, followed by the elimination of these conditions or at least some course of preventive action,

- manuel or automatic monitoring of the most suspect areas of the mine including the return airways of the working faces.

The methods of fighting a fire which may have spread into the gallery despite all the preventive measures applied are also quite conventional ; these include in particular :

- in some cases, direct extraction of the heated coal,

- in some cases, modification of the flow of air in order to suppress or to restrict the quantity of air feeding the fire,

- in most cases, obstruction of the channels feeding air to the fire, by means of stowing or injection of materials either mineral or synthetic,

- finally, if all the above courses of action have failed, construction of a sealing wall as air-proof as possible, in order to seal off the area, in most cases a working face, followed possibly by stowing of the area thus isolated.

The conventional methods of prevention are very heavy indeed, and the fighting of self-heating is generally a long and difficult task which can be dangerous in some cases and always very expensive.

3 - THE UTILISATION OF NITROGEN

The use of nitrogen for dealing with coal deposits which are susceptible to self-heating has completely changed the situation both for the prevention of heatings and actual fighting of declared fires. Nitrogen permits to inertinize the air flow which is reponsible for the first occurrence

and development of a spontaneous heating ; indeed, it is not possible during actual mining operations, to suppress the flow of air or at least to restrict it to a level at which it is ineffective whith regard to the self-heating of coal.

For the purpose of prevention, the injection of nitrogen is currently applied in goaf areas of the production faces at Blanzy Collieries in the Centre Midi, and at Sainte-Fontaine Colliery in Lorraine. The quantity of nitrogen injected can vary depending on the conditions on the face and on the air flow to be inertinized i.e from 50 m^3/hour to several hundreds of m^3/hour. In this type of utilisation, the objective is to maintain at a level considered as non hazardous, the content of oxygen in the air which leaks through the goaf. For this purpose, plastic tubes are placed at regular intervals in the goaf ; these tubes enable to take samples of the atmosphere (figure 1 and 2) in the goaf area. At the same time, steel pipes connected to the nitrogen mains are abandoned in the goaf. In the example of fig. 3, which is practised in the sublevel faces to Blanzy mines these two pipe systems which serve for injecting nitrogen and taking samples, are in fact the same, as the plastic tubes for sampling are placed inside the steel pipes for injecting nitrogen.

However this method of prevention cannot be applied in all working places. Moreover, it can be insufficient in some particular cases. However, nitrogen is also used for fighting self-heating that occur in these conditions. In fact, the utilisation of nitrogen in these cases, is very similar to what is done in prevention. The difference is mainly in the quantity of nitrogen used which can attain 1 000 m^3/hour and more. The injection is made by using the prevention pipe system if it exists or additional pipes that are installed at appropriate time. At this stage of intervention, it is often necessary to identify the path followed by the nitrogen in order to verify that the injection is effectively made to the source of heating. The control of this is also made by the system of collecting samples which must in any case be installed in all panels of coal which are liable to self-heating. By taking samples, it is possible to measure the content of CO at different locations of the goaf area. These samples also permit to measure the oxygen content at such points and this enable to identify the path followed by the nitrogen injected.

In some difficult cases, a tracing gas is used i.e sulfur hexa fluoride (SF_6) which presents the advantage of being measurable in traces i.e ppb (parts per billion). Of course, this phase of fighting a coal heating must be supplemented by appropriate measures to seal off the area of the goaf involved. The treatment of goaf areas that have been closed for some time and in which a heating has declared, for example due to strata movements having created air leaks to the closed areas, applied the same methods.

If the above course of action have failed, and in the case of a declared fire, the type of intervention must change in nature and more particularly in intensity. At this stage, it is generally no longer possible to attempt only a confinement of the goaf area and to maintain the area open. It is generally necessary to seal off the area completely from the air current by means of seal walls. In the case of conventional methods, the building of a sealing on the air-intake side of a fire is a relatively simple operation although it requires some time. However, the building of a sealing on the air-return side is a very difficult task and it can even be impossible in some cases. There is therefore a risk of having to abandon the idea of building such a sealing, at least in the first stage of fire fighting. Then there is a possibility of an explosion occurring in the fire and this imposes to make a very heavy sealing on the air-intake side in order to resist an explosion and protect the me fighting the fire.

The use of nitrogen has condiderably changed these methods of fire fighting. Indeed it is possible by simultaneously restricting the flow of air to fire and by controlling the flow of nitrogen injected, to render the atmosphere of the area ineffective with regard to combustion. The result is that the sealing on the air-intake side can be considerably lightened. In fact it can be made in simple wooden boards sealed with a sheet of plastic. The construction of such a sealing is therefore very rapid. Moreover, because the injection of nitrogen can be increased without waiting for the completion of the sealing, the actual fighting of the fire is much more rapidly effective than with conventional methods so that the extension of the fire is smaller. The quantity of nitrogen to be used in such cases varies from 6 000 to 20 000 m^3/hour. Modern technology enables to achieve such high flow rates of nitrogen.

At this stage, the use of nitrogen also enables to undertake the next operations of fire fighting very differently as compared with conventional methods. Indeed it is possible to select between 2 courses of action i.e either to seal off the area completely or to reopen it at short term.

If it is decided to seal off the area completely, it can be done in condiderably easier manner and in increased conditions of safety. On the air-intake side, the simple sealing made previously can be consolidated, in order to provide it with the characteristics required for the time when the injection of nitrogen will be stopped. These characteristics are air-proofness on the one hand and the resistance to a possible explosion on the other hand. On the air return side, the advantage of nitrogen is still greater as it is now possible not to wait until the fire is extinguished before starting to build the sealing. The injection of nitrogen is maintained while

construction of the sealing is being done. The injection of nitrogen allows to avoid the risk of an explosion and ensures that the temperature of the combustion gases flowing in the return airway is acceptably low. However it is necessary to work with breathing apparatus, at least until a first light seal has been completed and secondary ventilation with a booster fan can be installed. After this, consolidation of the seal can be pursued in similar conditions as on the air-intake side.

When an area of the mine has been sealed off in such manner, its reopening after some time is much easier, as the possibility of maintening some small level of injection of nitrogen permits to extinguish the fire completely and to avoid its starting up again when ventilation is resumed. If any tendency of the fire starting up again is apparent, because the fire fighting facilities remain in place, it is possible to control it at all times.

It is also possible to consider a reopening of the area rapidly if the fire has not extended too much. In such case, the sealing on the air-intake side does not need to be made. Control of the reopening is then made as above, by decreasing progressively the injection of nitrogen and controlling the effect thereof. It is always possible to seal off the area if necessary, until a new attempt to reopen it is decided upon.

Finally, the use of nitrogen permits intermediate solutions i.e the sealing off of the area by a light sealing with massive injection of nitrogen while the equipment is being recovered and then complete sealing off with more extensive methods when this operation is completed.

4 - FACILITIES FOR THE SUPPLY OF NITROGEN

Facilities for the supply of nitrogen have changed since our first experiences. They are also adapted to the estimated level of self-heating hazards of a particular production unit.

In our first experience in 1976 at Rozelay Colliery at Blanzy in the Centre Midi basin, nitrogen was delivered to the mine surface by tank trucks equipped with atmopheric heaters ; from the surface, is was transported to the face underground, by a pipe system which was normally used for flushing slurry from the surface. A similar solution was applied for a long time in coal mines which present minimum risks with regard to self-heating of coal. A contract with the French liquid air company "Société de l'Air Liquide", allows to apply this method very rapidly in any of the French coal mines. The flow of nitrogen can attain 10 000 m^3/hour.

Since that time, the main consumers of nitrogen have developed fixed installations. At Houillères de Blanzy, a reserve capacity of 50,000 l of liquid nitrogen is available at the surface of each colliery (figure 4). Fixed evaporators, which operate either in atmospheric conditions or with hot water, supplement the above facilities. A specialized network of pipes is installed in the shaft as well as in the main infrastrutural roadways and in the main gates of access to the production faces. These fixed facilities can further be supplemented if required by making use of the mobile tank trucks mentioned above.

More recently, a fixed connection has been installed between the nitrogen producing plants and the main pits of the Lorraine basin. The supply of one colliery by this system is now effective. The normal flow of nitrogen is 4,000 m^3/hour, and this can be rapidly increased to 12,000 m^3/hour in case of emergency. The previous fixed facilities have also been maintained and this can further increase the supply of nitrogen if required.

The use of nitrogen in French coal mining is developing, particularly in Lorraine as shown by the following table (fig. 5)

5 - EXAMPLES OF THE USE OF NITROGEN

5.1 - Systematic and continuous injection of nitrogen in the goaf of an operating face - ROZELAY colliery.

The first experience that was made with this type of application was at Rozelay Colliery of Blanzy in the Centre Midi basin in face S 61 ; this was a face with little methane gas, the seam thickness was approximately 6 m and the slope was nearly 15° (fig. 6).

The face length was 120 m and its speed of advance initially was 1.30 m/day. The CO content in the return airway of the face, where the quantity of air was approximately 9 m^3/s, was monitored by a UNOR CO measuring unit ; this unit was installed in the Gardon gate and the CO content was recorded at the surface on the televigile monitoring system.

The injection of nitrogen was undertaken from the surface by a fixed installation supplied by Union-Carbide in July 1976 ; this installation comprised of the following :

- 2 liquid nitrogen tanks of 37,000 liters capacity ; (subsequently there were 3 tanks of 37,000 l),

- 1 atmospheric evaporator of 500 m^3/hour (subsequently increased to 4 x 500 m^3/hour),

- 2 expansion pressure-meters for high flow capacity mounted in by-pass,

- 1 rotating flow-meter enabling 0 to 500 m^3/hour flow rates.

Figure 7 shows these facilities.

The nitrogen gas was injected from the surface by means of the slurry flushing mains and it arrived at the main gate and tail gate of the face. Then it was injected to the goaf area by means of pipes which were abandoned in the goaf and which were displayed either in the gate either in the goaf of the sublevel face i.e parallel to the face line.

A system for controlling the injection of nitrogen, based on the following principles was put into service :

- analysis of gas samples taken from the goaf area by means of plastic tubes left inside the pipes used for injecting nitrogen gaz,

- results of temperature measurements obtained by thermal transducers in the goaf of the face,

- monitoring of the return airway of the face.

The face started on 15 June 1976 ; it had made an advance of 25 m when nitrogen injection was started on 13 July 1976 at an average flow rate of 100 m^3/hour. The control of the flow rate and selection of the mains effectively used for the injection depended on the readings supplied by the UNOR CO measuring unit in the return airway of the face and on the analysis of the atmosphere in the goaf area.

The diagram of figure 8 indicates as a function of time, the CO content of the face return airway versus nitrogen flow rate used during the period extending from 23 August 1976 to 16 November 1976.

In the first phase of the life of the face i.e from 13 July 1976 to 77 August 1976, there was no cause of alarm and the nitrogen flow rate remained at 100 m^3/hour.

After 23 August 1976 the following events were observed simultaneously :

1. An increased emission of CO in the return airway. This content reached 22 ppm on 20 september,

2. The non return to zero of the CO contents of the face return airway on non working days.

- A content in O^2 which decreased only very slowly in the zone between the abandoned gates of the face and the initial face development heading and only slowly in the goaf of the face.

The flow rate of nitrogen was then increased up to the maximum possible of 500 m^3/hour which was reached on 27 september. Moreover, sublevel mining by drawing of coal from the goaf of the face was discontinued from 20 semptember to 30 semptember corresponding to a distance of advance of 20 m of the face. This action was taken in order to create in the goaf a barrier which would be lesse permeable than the one previously constituted by caved coal not drawn out from the goaf and rocks fallen from the caved roof. Finally, after 20 septembre, in order to cope more efficiently with point 3 above, the blind ends of the main and tail gates were systematically sealed with synthetic foam injections.

The return to zero of the CO contents in the return airway was obtained after 27 semptember. This permitted to resume the drawing of coal from the goaf but all the other measures were maintained i.e nitrogen injection at 500 m^3/hour, injection of foam and the daily advance of the face was increased to 1.80 m/day.

The decrease of the O^2 content in the goaf became significant and stable only after the first week of November, and then the nitrogen injection was decreased to 200 m^3/hour. The rate of advance of the face was maintained at 1.80 m/day then onwards and the sealing of gate-ends with foam was continued systematically.

CONCLUSION

All the measures that were taken, particularly the injection of nitrogen in the goaf and the sealing of the gate-ends with foam enabled to achieve the following :

- a better control of the disoxygenation of the atmosphere in the goaf,
- to obtain in the goaf at a distance of approximately 50 m behind the face line oxygen contents lower than 10 %,
- to correct the evolution of CO content in the face return airway and to decrease and maintain these contents at an acceptably low level.

The cost of these measures is certainly not negligible but they must be offset with the risk of losing at short term a sizeable production of coal :

- the risk of losing the mining equipment of a highly mechanised longwall face ; such equipment can be estimated to be of the order of 10 million French Francs,

- the delays and additional expenditure necessary to find in another part of the mine the capacity of coal production thus lost.

5.2 - Control of CO content in old face working (face B 2/2) - Sainte-Fontaine Colliery

Situation : (fig. 9)

The plan view presents the situation of the face the initial layout comprised of the main-gate, the air-intake and the face development heading. The face retreated on its main gate and advanced on its tail gate until it intersected the cross-measure gallery situated at the left of the panel. Then it continued its progression in the same conditions, on the left of this cross-measure gallery. It was decreased in length due to faults and was eventually stopped when it reached the end of the panel.

Characteristics of the seam :

At the roof of the seam, a bed which was part of the same seam was abandoned. Moreover there was another seam very nearby in the roof.

Ventilation :

During the entire mining of the panel, the pattern of ventilation was diagonal with the return situated in the first cross-measure gallery then in the second ; the flow of air was between 25 an 38 m^3/s.

Control of CO :

A unit for monitoring the CO contents, "UNOR", monitored the return of face, while another one controlled the ai-intake.

The tail gate, which was left open, was bordered by a gate end pack made with anhydrite. This zone of the face was traversed at regular intervals by 150 mm of dia hydraulic stowing pipes and by measuring tubes for controlling CO, CH_4 and CO_2 in the atmosphere of the goaf. As a rule, the controls were made by taking samples which were analysed at the surface. One of the tubes was connected to a "UNOR" unit and the signals produced by the unit were sent to the surface.

The main gate was isolated from the goaf by an anhydrite pack. it was left open but sealed off every 30 m approximately by a seal wall made with anhydrite. 150 mm dia pipes destined for the injection of nitrogen, penetrated into the goaf area at regular intervals.

Control of CO by nitrogen injection :

A diagonal pattern of ventilation favours self-heating of the gob. This is why a control of CO was particularly necessary and appropriate measures for fire fighting including nitrogen had been provided.

The CO content of the face return airway rapidly showed CO contents of 10-12 ppm. The CO content was even much higher in the measurement tubes.

The level of nitrogen injection was adjusted to a flow such that the CO content remained stable at 10-12 ppm in the return airway of the face.

It can be noted that the flow rate of nitrogen varied during the entire duration of mining operations.

Every time it was decided to decrease the flow of nitrogen, an increase in the CO content was noted between 24 and 48 hours after this action. Due to the high cost of nitrogen, the mine operator always tries to limit the consumption of nitrogen to the minimum possible level, depending on the particular geographical conditions and on the rate of production of CO.

This panel was mined up to completion without any incident.

5.3 - Extinction of a heating in old workings isolated by seals.
Seam F - Ste Fontaine Colliery

Location (fig. 10)

Seam F is located between levels 850 and 660 meters. The district had been isolated from the ventilation flow at the lower by means of an anhydrite sealed wall and at the upper level by a plaster seal.

During mining operations, the face had experienced a heating in 1981.

Measurements of the atmosphere made regulary behind the seal wall gave evidence of only a slow decrease of O2 but there were no traces of CO.

Incident

On 28 August, measurements made in the network of sample collection in underlying old workings gave the alarm.

On 30 August the sample taken behind the seal wall at level 660 m showed a CO content of 4.500 ppm. This CO content reached 6.800 ppm in the afternoon of the same day.

Rapidly, nitrogen was supplied to the lower level seal wall and the flow of nitrogen was made stable at 500 m^3/hour.

Nitrogen was maintained during the operations of reinforcement of the lower level seal wall as well as during the sealing off of the two walls and fissures that were found in the cross-measure galleries at level 850.

Conclusion

300 m^3 of hydraulic stowing enabled to seal off completely the old workings. When the CO content remained stable at zero level, the injection of nitrogen was discontinued.

5.4 - Inertinization of a face in order to extinguish a fire.
Seam F - Ste Fontaine Colliery

Location (fig. 11)

The panel of seam F/1 is situated between levels 850 and 930.

Its tail gate is air-intake. The layout of this face is irregular ; in particular, it presents a low near the entry.

Geometrical characteristics

- length of the tail gate : 350 m
- length of the main gate : 402 m
- face length : 245 m
- face height : 3 m
- average slope of the face : 17°

Characteristics of mining

- The face was retreating on its 2 gates.
- Ventilation was descending with a flow rate of 21 m^3/s. It must be noted that a configuration like this is in principle favourable for decreasing the risk of self-heating ; this is because of gas which fills up the goaf of the face and which is more stable and nearer to the face line.
- The methane content in the intake airway was 0.2 % CH_4 and 0.6 % in the return airway.
- Control of CO was not yet ensured by a UNOR unit in the tail gate because the face had only just started. However a UNOR was installed in an infrastructural main roadway on the main return level and this appropriately permitted to monitor CO in the face.

Situation of face operations on the day of occurrence of the incident (17 May).

The shearer had only just started as it had completed its 9th shear cut.

The face line was crossed by 3 fault zones i.e :

- one at 90 m
- one at 140 m
- one at the top of the face.

The section of the face between 90 and 140 m was disturbed by a buckling of the seam and there were roof falls at front and above the canopies of the supports in this area.

Caving of the roof had occurred in the section of face between 45 m and 130 m. In the faulty zones, the presence of shaly sand-stone layers caused some difficulties for the shearer.

Brief description of the incident

During the shearing of the 9th cut and in the faulty area at 140 m of the face line, the drum of the shearer was surrounded by a yellowish light which disappeared rapidly. Controls were immediately carried ; out there was no evidence of any anomaly. It was 19.00 hours.

At 20.50 a support operator saw blue flames above the support canopies at about 90 m from the main entry of the face. The personnel was then occupied in an attempt to extinguish these flames above the support canopies between 90 and 140 m of face line. In particular flames were burning at the front of the face in the fault zone situated at 140 m.

The extinction of the fire was only temporary and the flames started again.

There was no reversal of ventilation and two sudden flow of air occurred.

At 23.15, CO contents were observed on the UNOR measuring units of the 2 return airways.

At 0.10, the order of evacuation was given.

The Fire fighting operations

A light seal barrier was built around 01.00 a.m. in the tail gate of the face which was intake airway.

Simultaneously, a pipe mains was arranged for injecting nitrogen ; this was the compressed air mains of the tail gate of the face, which was being used for this purpose and connected to the nitrogen injection network installed in fixed position in the main cross measure roadway.

There onwards, the sequence of events was the following :

- 01.18 Nitrogen was injected at 3 000 m^3/h
- 02.33 " " 5 000 m^3/h
- 02.43 " " 7 000 m^3/h
- 06.10 " " 8 000 m^3/h
  air flow to the face was 10 m3/s
- 11.00 " " 9 000 m^3/h
- 12.00 Arrival of the equipment of Messer Griesheim, supplier of nitrogen of the neighbouring Sarrois coalfield with which there was a reciprocal assistance agreement.
- 14.00 Nitrogen was injected at 14 500 m^3/h ; the air intake to the face decreased to 7 m^3/h
- 15.15 Nitrogen at 17 500 m^3/h
- 15.22 Beginning of filling of the water siphon installed in the tail gate
- 23.10 Completion of the siphon filling. At that time there was only nitrogen in the district.

CO readings disappeared from the UNOR units at 18.30.

The filling up of the siphon was conducted while the mine was evacuated.

On the following days several reconnaissance visits were made to the main gate of the face ; these visits showed that :

- the face and its equipment had not suffered any damage,

- the blower of methane at 140 m of the face line had been the cause of the incident.

The flow rate of nitrogen was decreased to 7 500 m^3/h on 19 May. On 23 May, the water of the siphon was pumped out and mining operations were resumed on 24 May on the morning shift.

None of the methods of fire-fighting previously used would have made it possible to re-start work on the face after such a short delay : one week after the fire.

5.5 - Extinction of a conveyor fire in a metal mine.

In order to carry out extraction of an uranium mine an incline shaft was being sunk. A 700 m length had already been sunk with a slope of 25 %.

The incline was equipped with two conveyors :

- the first, downwards, had a reserve belt allowing the progression of the front to be followed,
- a second, upwards had its driving head above ground. It had a length of about 650 m.

Ventilation was ensured by ventubes and air-lines suspended above the conveyors.

The incident occured at the beginning of a shift around 5 o'clock in the morning. The weather was humide and a light drizzle was falling on the ground and on the unprotected conveyor driving head.

In the absence of the driving head foreman the motors were started by another employee while the rest of the personnel descended to take over from the night shift.

Soon afterwards a glow appeared at the driving head : this was the start of the fire. The driving drum rubbing against the belt had initiated inflammation of the rubber.

A by-stander stopped the motors and attempted to smother the beginning of the fire using the powder extinguishers nearby but without success.

Realizing his inability to stop the fire, the worker alerted to above-ground and mine personnel by telephone. It was around 5.15 a.m. At this point, the conveyor belt broke and the lower section, guided by its supports fell downwards into the incline.

At around 5.30 a.m. all the mine personnel had returned, safe and sound, to the surface. While passing near the

flames activated by the mine ventilation, they attempted to extinguish them with the numerous extinguishers dispensed all along the inclined shaft. They also managed to locate the fire at about 70 m from the shaft opening. The belt had folded-up leaving a free passage way on the side.

Secondary ventilation was stopped.

By this time, a thick black smoke was issuing in bursts from the mine shaft : heat was progressively increasing and convective currents were being set-up, with fresh air entering the gallery at the lower part of it and hot smoke issuing from the upper part.

After reviewing the advantages and desadvantages of several possible methods of extinguishing the fire the following steps were taken ;

- a barrier was constructed at the shaft entrance in order to reduce, if not eliminate, air introduction into the shaft. Pipes and an air-line were placed across the barrier,

- liquid CO_2 was introduced behind the barrier. This gas was chosen in place of nitrogen because of the characteristics of the location, in particular because of the steep slope. It was hoped that the high density CO_2 would rapidly replace the air in the shaft. Attempts were made to locate the quantity of CO_2 required to fill the shaft (8 000 m^3). By 9.30 a.m. a truck had been located with a CO_2 supply of 30 t (10 000 m^3 under normal conditions). It was sent to the mine with the required personnel.

Introduction of CO_2 began at 15 h. During the operation, the air-line across the barrier allowed the smoke to escape. The concentration of CO_2 in these gases only increased to over 2 % at around 17.30 at the end of the CO_2 introduction.

The following day a reconnaissance visit was made by a rescue team from the Cevennes Coal Basin who came specially equipped with respirators. They observed high concentrations of CO_2 and an absence of oxygen and smoke.

A second visit made it possibles to observe the burnt piled-up belt which was still red-hot. The surrounding metal was also at high temperature.

Water sprays were used to lower these temperatures and finish the extinguishing of the fire.

All that was left to do was to purge the poisoned atmosphere. This was done with a double ventilation system. Thirty hours after the start of the fire the atmosphere, right to the bottom of the mine, had returned to normal.

The use of CO_2 to render inert the mine atmosphere thus allowed bringing the fire under control at low cost and without damage to equipment. It also made it possible to return the mine to normal conditions after only a brief delay.

Finally, and far from being the least important advantage of this method, all work was carried out by workers under safe conditions.

5.6 - Conclusions.

The use of nitrogen, while relatively recent, has profoundly altered prevention techniques and methods used to combat self-heating occurrences and mine fires.

In coal deposits that are suceptible to self-heating hazards, either due to the nature of the coal or to the mining method or to both simultaneously, the use of nitrogen has become practically indispensable, not only for small localized actions but also as a permanent ancillary to the coal production process.

Obviously the cost of this technique is not negligible but it can be expected that, by improving the management procedures in the use of nitrogen, this cost will be maintained within reasonable economic limits.

Nevertheless, we do consider nitrogen as a crucial asset for ensuring the safety of mining operations for some of our coal deposits ; moreover, and this is an appreciable premium, nitrogen guarantees the individual security of all the men working in such mines.

It is of course also necessary, in parallel to the use of nitrogen, to provide the means for localized protection of mine personnel. These includes :

- oxygen self rescuers (APEVA),
- refuge chambers,
- calculation methods to evaluate ventilation stability and research for methods to prevent inversions,
- methods to evaluate the flammability of underground atmospheres,
- fire studies in experimental galleries in order to develop a knowledge of combustion and extinguishing conditions and the composition of gases produced and to test detection systems.

6 - INDIVIDUAL PERSONNEL PROTECTION

The large scale means used to fight fires, as has been shown in the previous examples, allow bringing the situation under control only after delays of several hours or days.

Safe-guarding personnel thus requires use of techniques and means which can ensure immediate protection. The overall objective is to evacuate personnel from the mine, but this is hampered by the presence of more or less toxic smoke or oxygen dificient air : respiratory apparatus are thus necessary. If immediate evacuation is not possible due to the temperature or opaqueness of the smoke, the trapped personnel must have the possibility of awaiting rescue crews in specially-equipped refuge chambers.

6.1 - Oxygen self-recuers (APEVA) and refuge chambers

Filter self-rescuers have been obligatory in numerous countries for several years. These apparatus don't provide total protection however. They don't function satisfactorily in low-oxygen atmospheres or where CO concentrations are high.

France has not therefore imposed the use of filter sefl-rescuers, but has, in collaboration with l'Organe Permanent pour la Sécurité dans la Mine de Houille (Luxembourg) promoted research to develop an autonomous live-saving apparatus.

The first step was achieved in 1963 with the development of a compressed oxygen self-recuer (FENZY 63, later FENZY 66) which was systematically introduced in mines (near work areas) where instantaneous emissions occurred.

The second step was begun in 1977, during which the first "chemical" oxygen (produced by KO_2) apparatus for industrial use appeared.

These system are capable of supporting the lives of personnel for 90 minutes of active escape or 4 hours at rest conditions. French coal mines have over 4,000 such apparatus which are designated by the code APEVA.

The apparatus in present use have nevertheless the disadvantage of being relatively heavy (3 to 4 kg). We are presently looking to develop apparatus which are much lighter and which could be worn in work situations. They would have capacities sufficient to allow the wearer to go to a centralized depot where large capacity units would be available.

When the mine structures is such that part of the personnel is likely to have to await the arrival of rescue teams, we consider it essential to have refuge chambers available. These would allow protection from toxic and hot gases and would be equipped with a telephone link with the surface. Refuge chambers are dead ends on the side of galleries from which they are separated by an insolated barrier. They are

equipped with a compressed air supply and regulator which allow the feeding of breathable air.

6.2 EXAMPLE : Transformer fire in the Provence Coal Basin

A 630 KVA - 5 000 V/1 000 V tranformer located at the bottom of the mine shorted at the 1 000 V outlet contacts upstream from the low voltage circuit-breaker.

The three 5 000 V circuit-breakers above ground operated and it was not possible to re-start them before eliminating the problem in the mine. The ventilation blowers were therefore out of service hampering the circulation of air.

In the mine, the worker who noticed the transformer fire signaled an alert at 10 : 40 am. The personnel in the area, a total of 101 persons since the shift was changing, were alerted either because they saw the smoke or by telephone. Only 4 workers were not notified ; 39 managed to find a pure air circuit ; 49 took refuge in refuge chambers or in blind galleries equipped with compressed air. Another 7 workers, using oxygen self-rescuers (APEVA) managed to cut the electrical supply and fight the fire. After isolating the transformer it was possible to re-engage the surface circuit-breakers at 11 :20 am thereby re-establishing normal ventilation. The smoke was practically completely evacuated by 12 : 15 pm.

This example shows that a sizeable proportion of the personnel were unable to directly reach the pure air circuit, and were protected in refuge chambers until the end of the incident. Personnel which were required to penetrate into smoke filled areas to control the fire were able to do this with the help of APEVA units.

6.3 Research underway : fire test gallery

The gases emitted during mine fires represent a grave danger for mine personnel. It appears necessary therefore to study combustion conditions, opaqueness of smoke and gas emitted during the combustion of various material used in mines, as well as different fire detection systems.

A mine fire test gallery was therefore constructed at CERCHAR (fig. 12) and equipped with a gas treatment system.

The initial tests were carried out on belts from different types of conveyors. While the results are not yet sufficiently numerous to generalize, it is hoped that this work will considerably improve mine safety.

7 - PRECAUTIONS RELATIVE TO MINE VENTILATION AND MINE ATMOSPHERE

Mine fires result in the emission of gases in variable quantity and temperature level. These gases will be transported by ventilation currents ; the flow patterns of which can be considerably modified by the gas emissions. Examples of inversions where smoke was spread by ventilation systems are known in places where there were not expected. This phenomenon was the cause of the accident in the Combes Mine in France which claimed 48 victims in 1928.

The stability of the ventilation system in the case of a fire is thus of major importance for the safety of mine personnel.

In the gases emitted in a combustion reaction, it is possible to find combustible gases such as CO an H_2 as well as complex gases resulting from the pyrolysis of material in the mine. In certain mines methane is emitted from the coal deposit. It is extremely important to be able to determine, easily and rapidly, if the gas mixture is flammabe or not.

The discussion to follow will examine answers currently available to these two problems.

7.1 Ventilation stability

Upsets in ventilation which may be caused by the start of a fire underground have been studied for a ralatively long time. BUDRIK in Poland gave some qualitative conclusions but left a large measure of uncertainty.

His work was continued by experts at the Organe Permanent pour la Sécurité dans les Mines de Houille (Luxembourg). The development of equations describing theses phenomenon was carried out by E. SIMODE and later completed by L. VIELLEDENT.

This work led to the development of calculation programmes for standard computers and more recently, programmes for use on micro-computers such as the IBM-PC or the DEC MICRO PDP11.

The programmes are set up in such a way as to allow interaction with the operator who does not require special computer training, only a good knowledge of ventilation techniques.

In order to facilitate use of the programme, it was complemented by a graphics display programme operating a display unit linked to a MICRO PDP11 (fig. 13). It is thus possible to display the entire ventilation network (fig. 14) or individual sections (fig. 15) on the screen.

This system makes it possible to determine the effects of any ventilation modification or upset, and, in particular, to examine to consequences of the development of a fire.

Inversion risks can therefore be predicted and the appropriate steps can be taken to eliminate them.

The programmes which were already being used on the Lorraine Basin Central computer without graphics display have now been made available on micro-computers with display.

7.2 Flammability of gas mixtures

The laws governing inflammation of complex mixtures were first presented for use by miners, by workers at the U.S. Bureau of Mines in 1929.

In a paper by L. VIELLEDENT these laws serve as the basis for developing the algorithms necessary for their use in a computer programme.

We have developed a programme for use with a pocket calculator linked to a printer. The overall system was developed to meet the following conditions:

- autonomy with respect to the mains
- easily transportable,
- the programme must be stored in memory and be immediately available,
- the use of the interactive programme must be very simple.

The data necessary to use the programme are the concentration of :

- combustible gases CH_4, CO, H_2 and heavy hydrocarbon gases,
- oxygen,
- CO_2

It is assumed that the remaining gas is made up of nitrogen, the concentration of which is calculated by the programme.

The result calculated are (fig. 16) :

- The coordinates of the inflammability triangle,
- the coordinates of the point representing the atmosphere,
- the corresponding graph,
- the effects of modifying the proportions of one of the three components : air, nitrogen or combustible gas. This latter information is very useful during operations where

The various French coal basins are all equipped with this calculation system.

7.3 The case of gassy mines

When a large fire start in a particular area in the mine, in general, it is necessary to isolate the zone by barriers in order to smother the fire. The use of nitrogen before closing the stopping reduces the oxygen concentration in the air which feeds the fire.

A further reduction in the oxygen concentration can be achieved by reducing ventilation after the flow of nitrogen begins. This leads however to an increase in methane concentration in gassy mines. It is therefore necessary that these measures be taken with extreme caution in order to prevent the build-up of large volumes of combustible gases which represent serious explosion hazards. The inflammability of the gas mixture must be monitored using the techniques describes in section 7.2. The regulation of the flowrates of ventilating air and nitrogen respectively can be guided by the calculation methods developed by L. VIELLEDENT.

Taking into account these precautions, the use of nitrogen nevertheless allows isolating fire areas without risks of explosion by reducing oxygen concentration, thus reducing the fire intensity.

8 - CONCLUSION

Fire fighting in mines has made considerable progress in recent years due to the use of nitrogen.

- the development of self-heating phenomenon can be limited without compromising work in the mine.

- the damage produced by fires are much reduced and work can be re-started after only brief delays.

At the same time, safety has been considerably improved due to apparatus developed to ensure the start of a fire or self-heating occurrence.

If, by the use of prevention techniques, the number and seriousness of incidents are reduced and if the control methods are well-prepared in advance, fire-fighting in mine will be able to be carried out under safe conditions.

AKNOWLEDGMENT

The author wishes to thank Charbonnages de France and CERCHAR's Services for their support in the preparation of this paper.

ILLUSTRATIONS

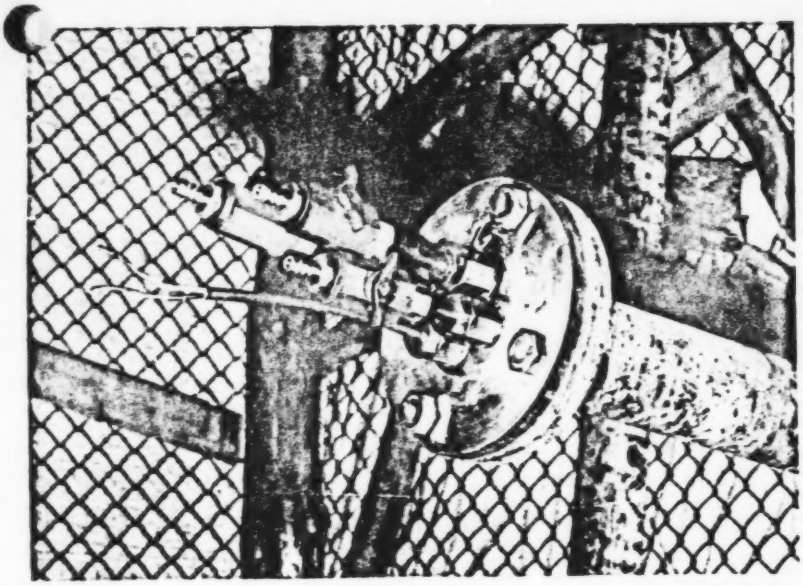


Fig.1 - Outer end of the sampling tubes in the goaf of a face

Fig.2 - Taking of samples in the goaf of a face

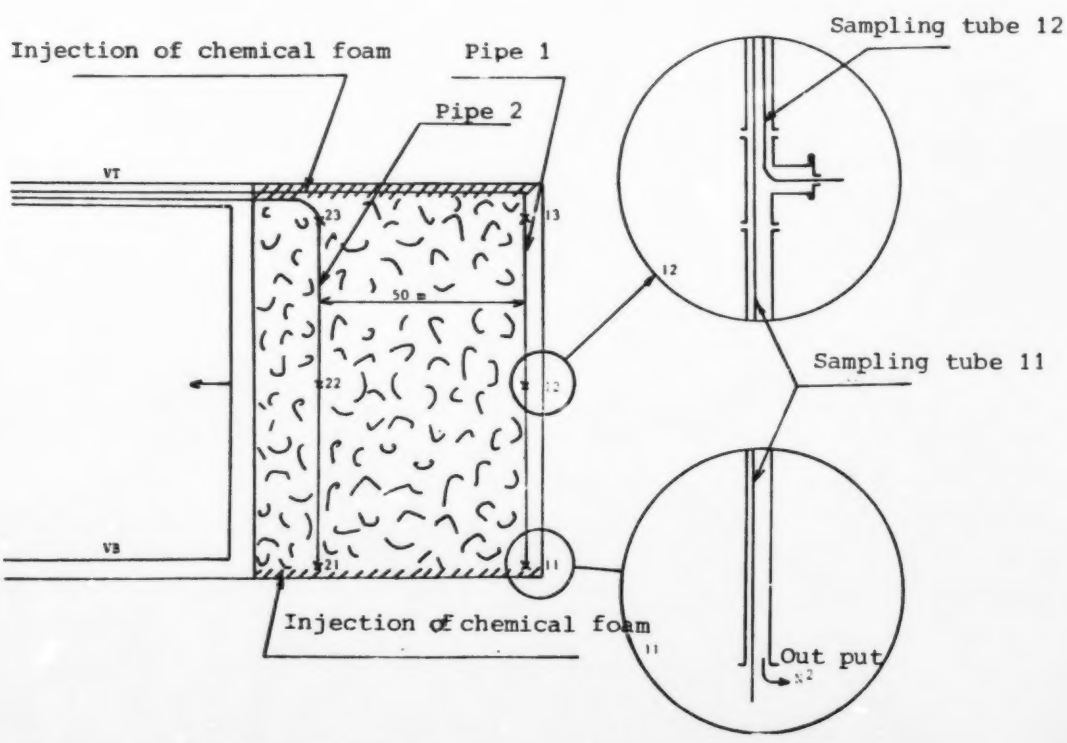


Fig.3 - Principles of the prevention of fires in the goaf of an underwinning face

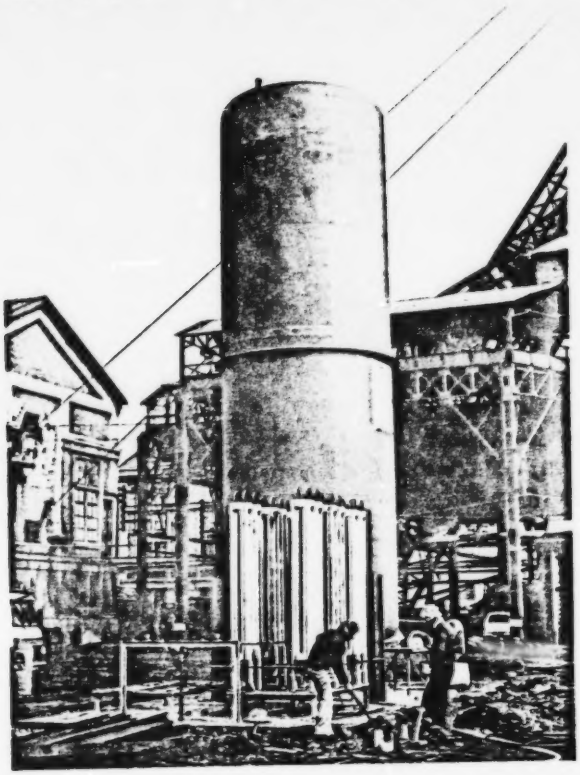


Fig.4 - Liquid nitrogen tank at the surface

CONSUMPTION OF NITROGEN IN LORRAINE BASIN

YEAR	m^3 expanded
1979	570.000
1980	4.090.000
1981	5.860.000
1982	16.260.000
1983	15.700.000
1984 (5 mois)	8.700.000

Table 5

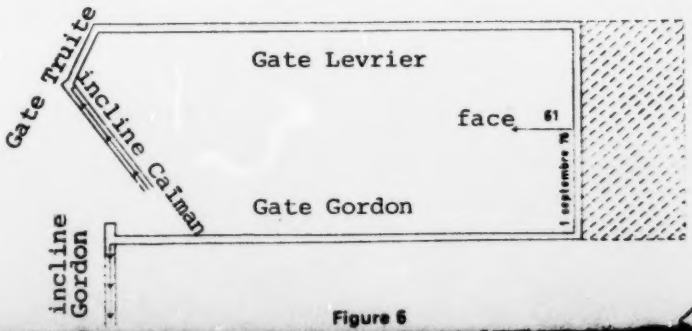


Figure 6

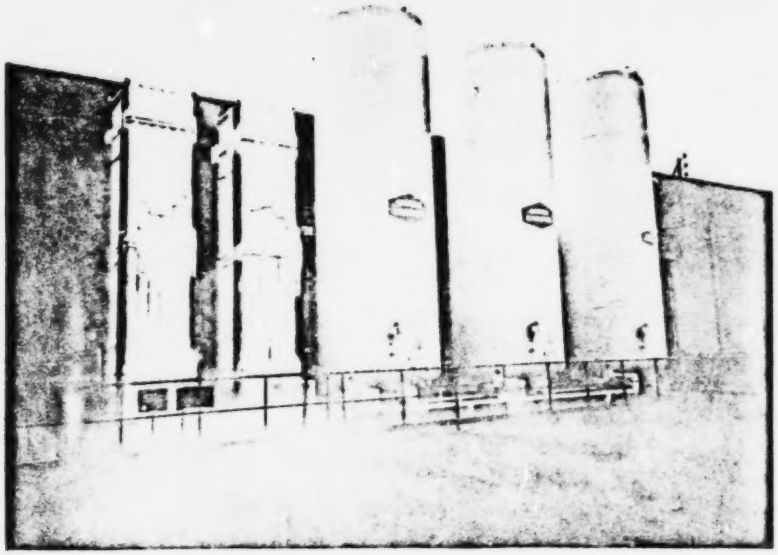


Figure 7

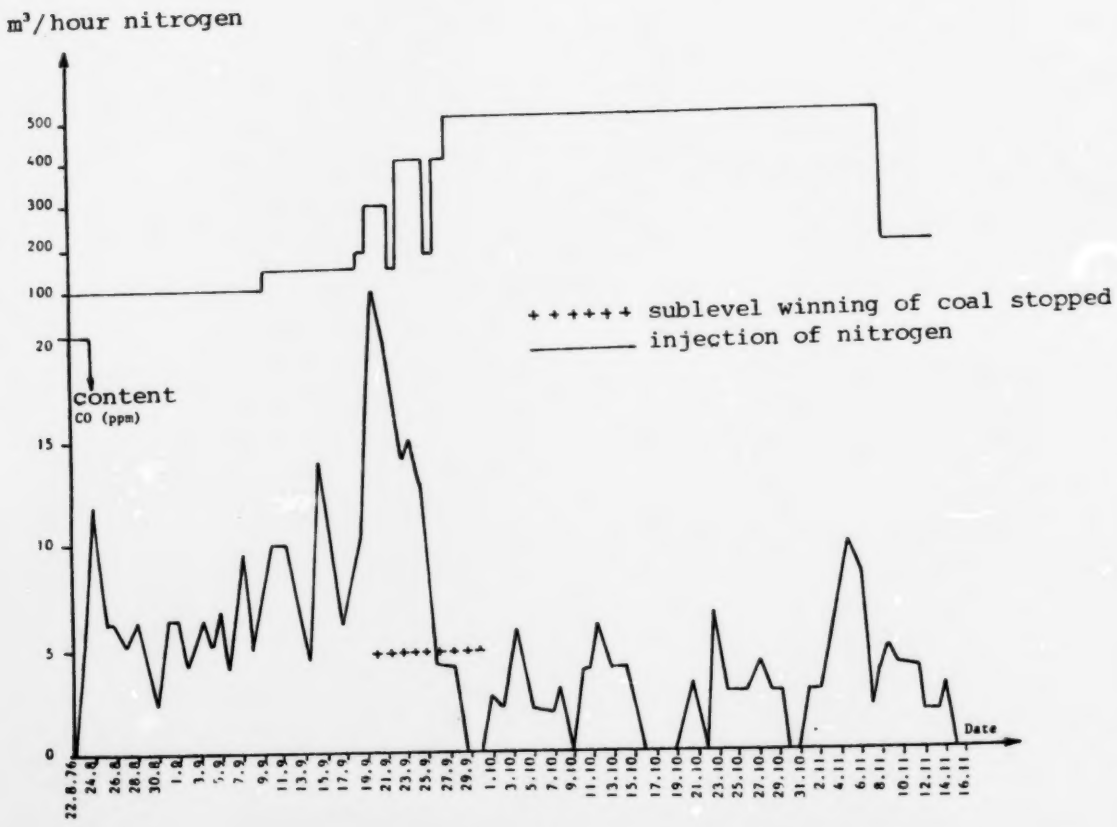


Fig.8 - Rozelay colliery - Face S61 - CO content in the return VS flow of nitrogen injected

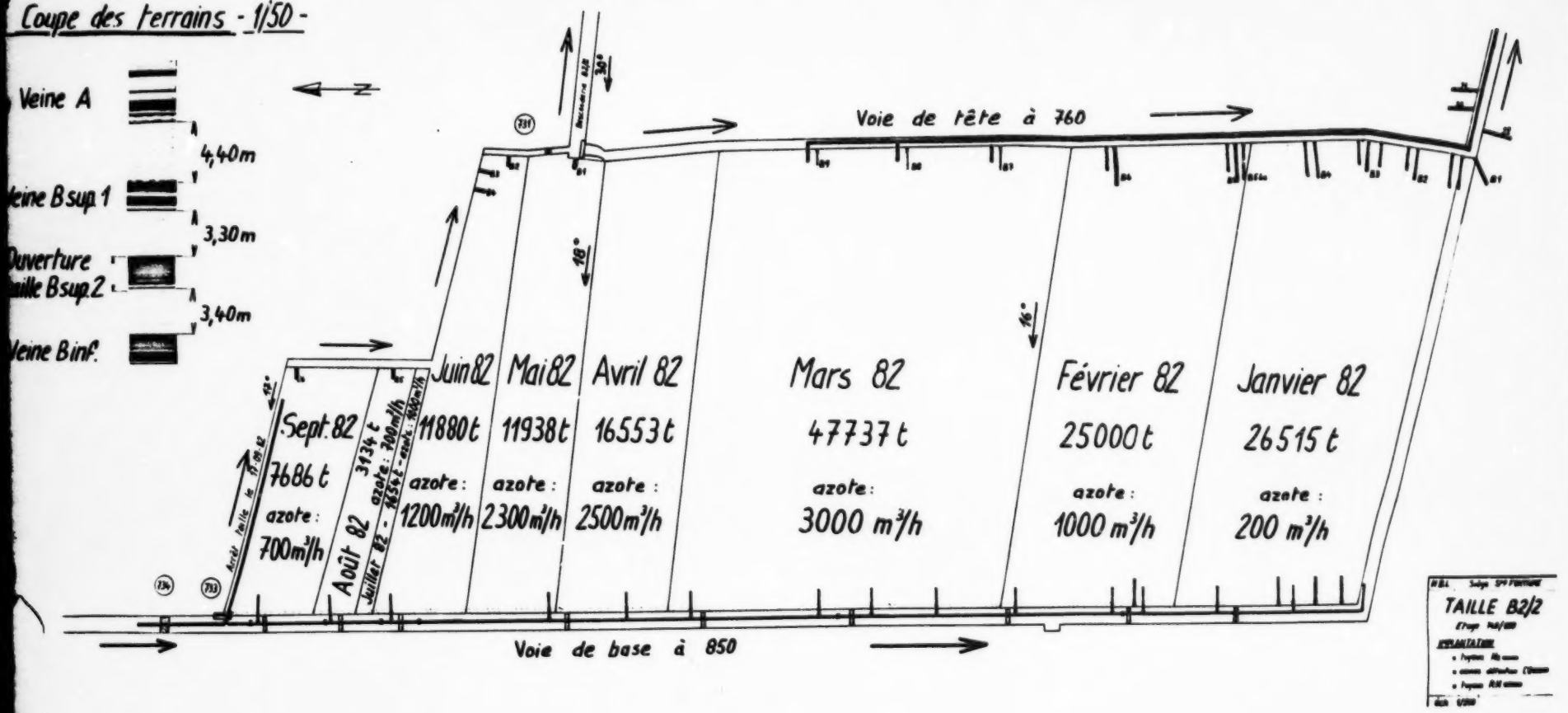
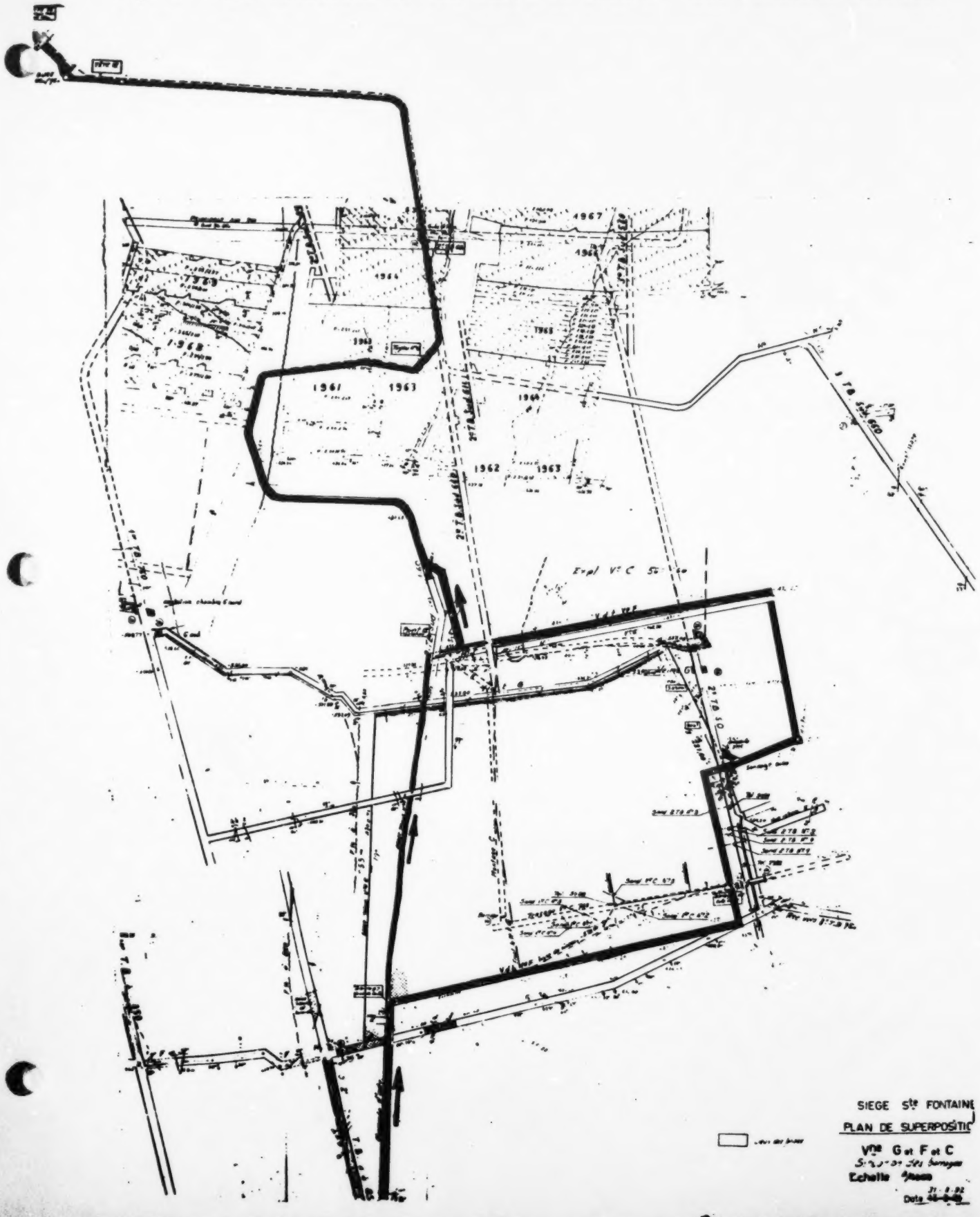


Fig. 9 - The situation of face B2/2 - SAINTE FONTAINE colliery

Fig.10 - The situation of the seals in seam F - Ste FONTAINE colliery



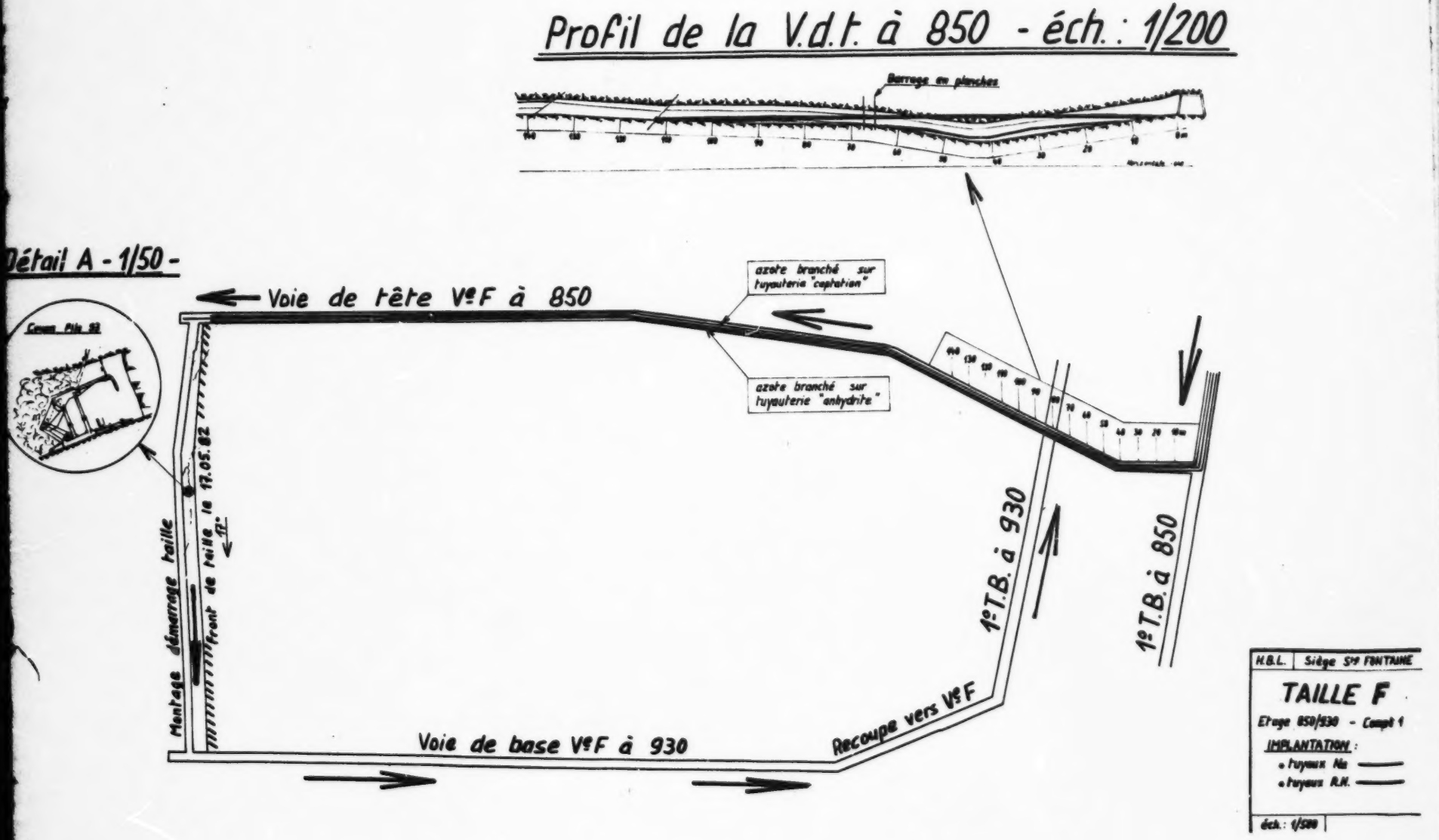
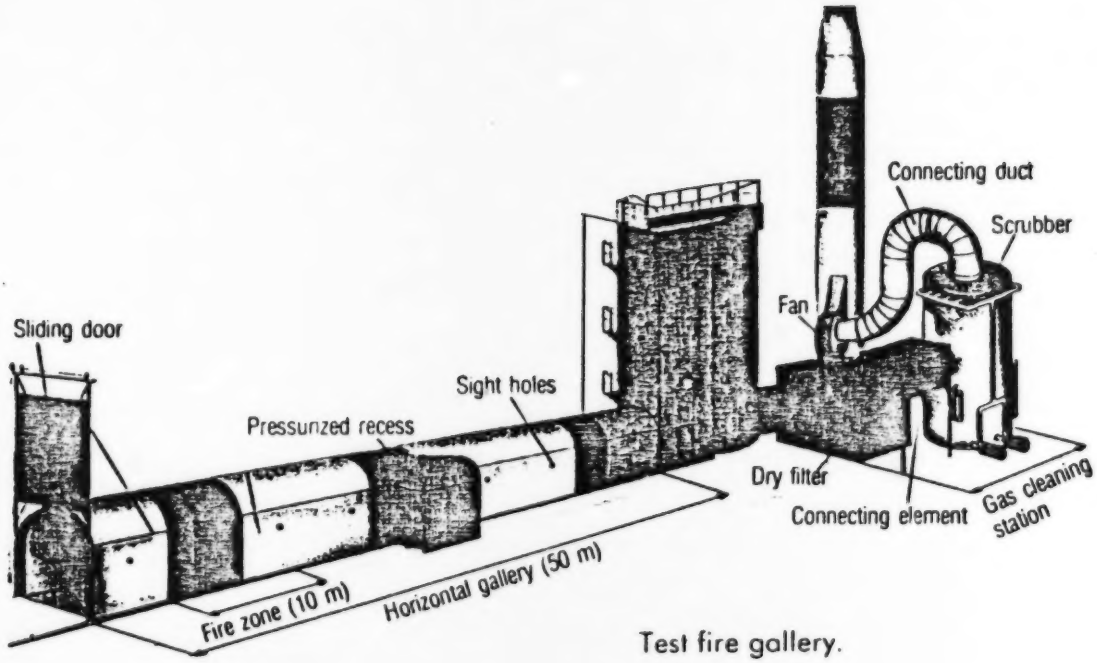

Profil de la V.d.t. à 850 - éch. : 1/200
Barrage en planches
Détail A - 1/50 -
Voie de tête VeF à 850
azote branché sur tuyauterie "captation"
azote branché sur tuyauterie "anhydrite"
Montage démarrage taille
Front de taille le 17.05.82
1°T.B. à 930
1°T.B. à 850
Voie de base VeF à 930
Recoupe vers VeF
H.B.L. | Siège St-F FONTAINE
TAILLE F
Etage 850/930 - Couche 1
IMPLANTATION :
• tuyaux Ne
• tuyaux R.N.
éch. : 1/500

Fig.11 - Face F 1 - SAINTE FONTAINE colliery



Test fire gallery.

fig. 12

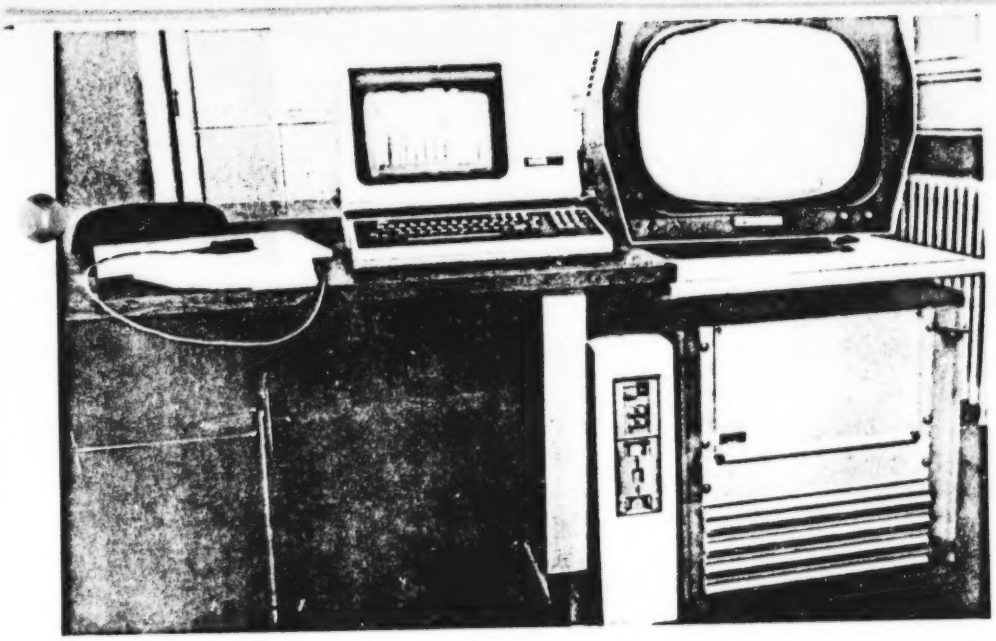


Fig.13 - Display unit and micro-computer

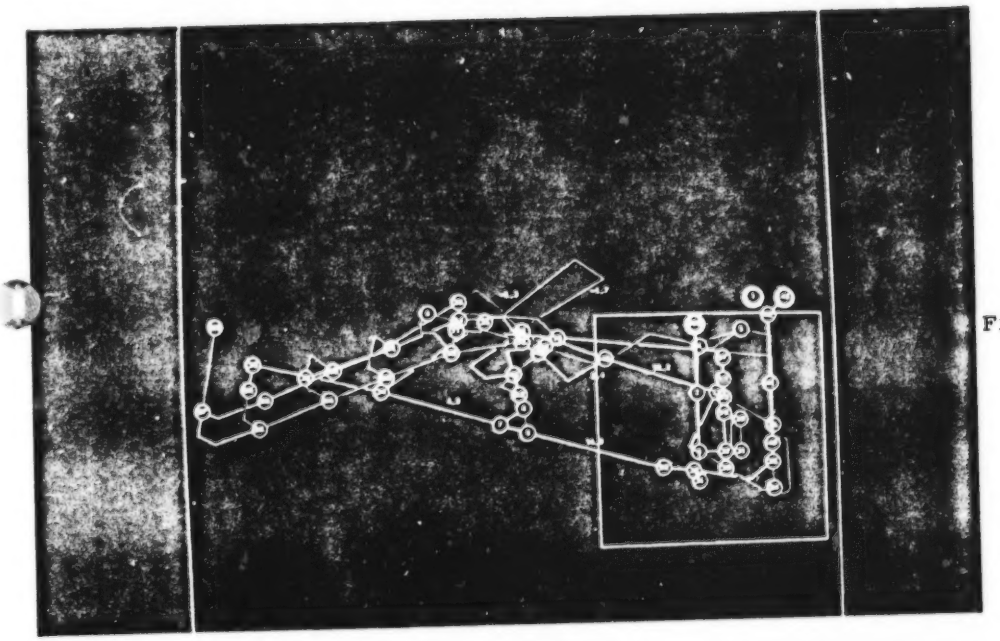


Fig.14 - Display of the entire network of a mine

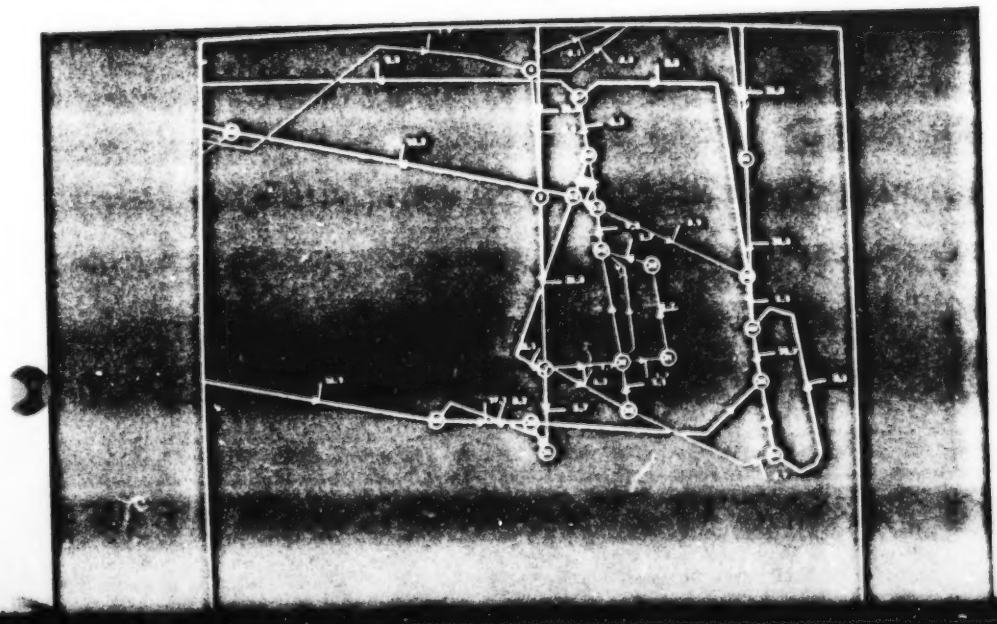


Fig.15 - Display of a part of the network

SAMPLE-01 9.42
24-08-84

CH4 : 6.40 %
H2 : 1.50 %
CO : 0.45 %
HGL : 2.30 %
O2 : 16.10 %
CO2 : 0.00 %
N2 : 73.25 %

X : 10.65 %
Y : 16.10 %
N : 73.25 %

XB : 4.34 %
YB : 19.99 %
XH : 17.47 %
YH : 17.24 %
XT : 4.82 %
YT : 10.34 %

P(X,Y) EN ZONE 3

	vol	zone
+	1.41	A 1
-	0.19	A 2
+	0.22	C 2
-	0.06	C 1
+	0.33	N 2
+	0.88	N 0

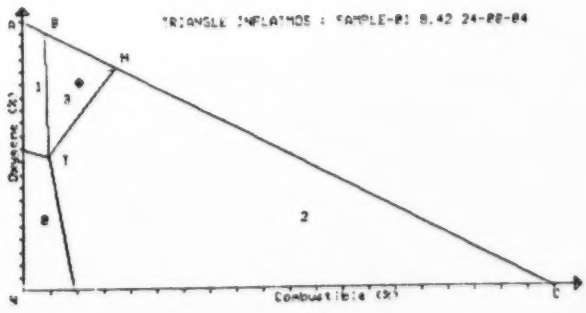


Fig.16 - Example of the flammability diagram of a gas mixture

AR-72.2

UNDERGROUND MINE FIRE CONTROL

SECTION 5

FIRE CONTROL WITH INERTING FOR CANADIAN UNDERGROUND MINES

by

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NOTE

The paper **'Underground Mine Fire Control With Inerting Systems'** summarizes a comprehensive CANMET report entitled **'Underground Coal Mine Fire Control With Inerting Systems - A Study'** (DSS File # 23SQ.23440-3-9035), completed in April 1984, which describes inerting technology and its potential application in Canadian mines. An important feature of the report is a set of twenty-two case studies (see Attachment 5A) covering inerting experience in a wide range of circumstances. The full CANMET report and the case studies are recommended reading for anyone who may be involved in the use of inerting techniques in Canada.

ATTACHMENT 5-A
LIST OF CASE STUDIES

Canada

Case Study #1 - #26 Colliery

Czechoslovakia

Case Study #2 - Doubrawa Mine
Case Study #3 - Fucik Mine

France

Case Study $4 - L'Herault Mine
Case Study #5 - Sainte Fontaine Mine
Case Study #6 - Rozelay Mine

Germany

Case Study #7 - Luisenthal Colliery
Case Study #8 - Osterfeld Colliery
Case Study #9 - Schlagel und Eisen Colliery

India

Case Study #10 - Laikdih Deep Colliery

Poland

Case Study #11 - Brzeszcze Mine
Case Study #12 - Staszic Mine
Case Study #13 - Zabrze Mine

United Kingdom

Case Study #14 - Daw Mill 15's Mine
Case Study #15 - Daw Mill 65's Mine
Case Study #16 - Fryston Mine

U.S.A.

Case Study #17 - Inland #1 Mine
Case Study #18 - Joanne Mine
Case Study #19 - Olga Mine
Case Study #20 - Peabody No. 10 Mine
Case Study #21 - River King Mine #1

U.S.S.R.

Case Study #22 - Conarnaya Mine

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

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July 1984

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COAL RESEARCH LABORATORIES
DIVISION REPORT ERP/CRL 84-22 (J,OP)

UNDERGROUND MINE FIRE CONTROL WITH INERTING SYSTEMS

by

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Attachment 5-A List of Case Studies

ACKNOWLEDGEMENT

In late 1983 CANMET entered into a contract with Associated Mining Consultants Ltd. of Calgary to conduct a review of the current status of underground mine fire control with inerting systems. This review provides Canadian mine operators and mine rescue organizations with an account of recent experience gained principally off shore. The final report (1) was accepted by CANMET in May 1984. Copies of this report can be purchased from CANMET's Technical Information Division in Ottawa (613-995-4029).

INTRODUCTION

Inerting is the introduction of an inert gas into an atmosphere in contact with a fire to reduce the level of oxygen and hence the intensity of the fire to the point of extinction. The benefits of inerting include:

a. Reduced Explosion Hazard

By displacing oxygen from the atmosphere surrounding the fire, the risk of secondary gas explosions is reduced. For example, the Coward triangle predicts that simple methane-air mixtures are non-explosive below 12% oxygen. In actual mine fires combustible gases may include hydrogen and carbon monoxide as well as methane. Such gases are also rendered non-explosive with oxygen removal to below 4%. Fuel rich oxygen deficient mixtures can however be made explosive through dilution with air. Such dilution can occur downwind of the fire. It is also important to remember that the atmosphere in a sealed off fire zone is rarely homogenous.

b. Reduced Fire Intensity and Spread

In a fire zone the initial combustion may well set alight materials surrounding the fire. Inerting can reduce the intensity and spread of secondary combustion and can cool the area surrounding the fire zone after the fire itself has been extinguished.

c. Reduced Air Leakage

Leakage of air into sealed areas in excess of the natural leakage may be reduced either by introducing inert gas into the leakage paths to replace air or by pressure balancing seals and providing a chamber of nitrogen on the outbye side of the seals. Both methods assist in the reduction of the intensity of combustion and hasten oxygen starvation.

d. Facilitates Re-entry

Inerting facilitates re-entry into sealed areas by limiting the heating up of strata around the fire zone, minimizing the explosion risk and reducing the temperature. Inerting with gases does not damage exposed equipment and facilities, which can be put back into service without major refitting, avoids the large post-incident costs that would be experienced if water flooding were used and can reduce the normally lengthy waiting period when seals are required.

INERTING SYSTEMS

Several different inert gases could be used for fire control, but considerations of availability, cost and other factors have focused industry's attention on three - gaseous combustion products (GCP), carbon dioxide, and nitrogen. Sufficient success has been achieved with these media in many parts of the world to provide a high degree of confidence that one or more is appropriate for Canadian conditions. Table 1 compares the advantages and disadvantages of the three inerting media.

Gaseous Combustion Products

Gaseous combustion products (GCP) generally contain a significant proportion of nitrogen along with carbon dioxide, carbon monoxide, water vapour and certain other constituents. GCP are generally low in oxygen and if brought into contact with a fire can reduce its intensity.

Though there are some reported cases of flue gases being conducted into mines for firefighting purposes, any practical method of using GCP must be mobile and provide at the fire site rapid generation of

GCP with appropriate chemical and physical properties. This can be achieved by using an inert gas generator (IGG). A number of such machines have been developed of which the most important are the Polish GAG (CMI) series and the Russian GIG series. The Polish GAG machine is available commercially and has been tested under contract by the USBM (2) (Figure 1).

In most designs the equipment consists of an aero jet engine with afterburner whose products are passed through a cooling system and discharged into the fire area through a duct. The output of these machines range from the Russian GIG-50 with a capacity of 120 m^3/min to the Polish GAG-3 with a maximum output of more than 1800 m^3/min.
A summary of the principal characteristics of these IGG's is provided in Table 2.

The composition of the GCP varies according to the type of generator and its operating parameters, though the principal constituents are always nitrogen, carbon dioxide and water. Typical products from a GAG machine have been stated to be composed as follows:

Constituents	Volume (%)	
	Case 1	Case 2
Water	64.10	63.80
Nitrogen	30.44	30.80
Carbon Dioxide	4.72	5.00
Oxygen	0.74	0.40

Oxygen contents quoted for IGG's ranges from a maximum of 3% for the small GIG-50 to less than 1% for the GAG-3. The exhaust gases generally leave the duct at a temperature between 80°C and 90°C, depending on operating conditions. The primary cooling water can be rejected to waste or can be injected into the evaporative cooler. In this case, the gaseous products are delivered a few degrees hotter than is the case if an external water supply is provided for the evaporative cooler.

In a more recent design of the GAG, provision is made to use nitrogen for evaporative cooling. The nitrogen enables the duct line to be purged before the IGG is put into operation and increases the proportion of nitrogen in the product.

The characteristics of an IGG are a high flow rate coupled with a relatively low delivery pressure. For this reason it is necessary to site the machine at or near the fire zone. The transmission of GCP some several kilometres through an 800 mm duct has been reported from Poland. Consideration has been given in Germany and Poland to modifying IGG equipment to increase the delivery pressure so that the unit may be installed on the mine surface and the products transmitted to an underground fire through pipes.

IGG's are not permissible for use in coal mines (i.e. are not flameproof). Coal mine users argue that permissibility is not very significant in a coal mine with an active fire however the IGG does represent a potential ignition source. Non gassy non coal mines do not use permissible equipment in normal circumstances so the permissibility question is not an impediment to IGG use in such mines. Given the geometry and fire risks in underground Canadian metalliferous and industrial mineral mines the IGG option is felt to be very favourable. Generation on site is also an advantage; particularly when remote location or adverse weather can make assured access to commercial suppliers of inert media tenuous or uncertain.

Carbon Dioxide

Carbon dioxide is widely used in fire extinguishing systems and was an obvious choice when a medium to inert underground mine fires was sought. It is a colourless gas with a density of 1.98 kg/m^3 STP. It is produced on a commercial scale in most industrialized countries and is available in relatively large quantities. It can be provided in solid form (dry ice) and as a liquid.

In some mine fire situations solid carbon dioxide has been transported to the fire zone and been placed on the fire. In other cases bottled carbon dioxide has been released directly into the fire zone or liquid carbon dioxide has been directed onto the fire through boreholes from the surface or released into the air stream or through stoppings. Should a large continuous flow of carbon dioxide be required, commercial evaporation units can be employed similar to those described below for nitrogen evaporation.

Though carbon dioxide has some advantages, the wide availability of commercially produced nitrogen with characteristics more suitable for inerting purposes, has significantly reduced the reported usage of carbon dioxide.

Nitrogen

Nitrogen, one of the principal constituents of air, is an inert gas with a density of 1.25 kg/m^3 STP. It is stable and can be stored or transported in liquid form. Nitrogen is available commercially and a number of nitrogen contracting companies provide specialized nitrogen services to the oil, gas and chemical industries. Nitrogen technology is well developed and is being increasingly applied for fire control in the underground mining industry.

Nitrogen can be delivered to a fire zone as a liquid or in gaseous form. The four principal delivery systems that have been used in actual mine fires are:

Liquid nitrogen : delivered by tanker into fire area.
Gaseous nitrogen: produced by air separation unit piped to fire area.
Gaseous nitrogen: produced by ambient temperature evaporation unit piped to fire area.
Gaseous nitrogen: produced by externally heated evaporation unit piped to fire area.

The volume of nitrogen required to handle the emergency is a major factor in selecting the delivery system. Using currently available commercial equipment gaseous nitrogen can be delivered at up to about 50 m^3/hour by an ambient temperature evaporation unit, up to about 300 m^3/hour by an externally heated evaporation unit and up to 13 m^3/hour from an air separation unit.

Where large flow rates are required only externally heated evaporators currently provide sufficient capacity and in most cases mine fires have been fought with units of this type. The evaporators have

generally been propane or diesel heated, or hot water has been provided from the mine hot water system or a locomotive boiler.

A pre-requisite for the delivery of liquid nitrogen by underground tankers is the accessibility of the fire zone to the mine transport network and the availability of specialty transportation vessels suitable for use underground.

Nitrogen inerting is a mature well understood technology in Europe. The West German underground coal mining industry has used nitrogen inerting during 63 separate incidents in the period 1974 to 1983 (1).

CASE HISTORIES

The contract final report (1) contains twenty two case histories that describe various successes and failures of inerting technology in underground mine applications throughout the world. Three case histories are summarized in this article to give the reader insight into the application of inerting technology during actual underground mine fire incidents.

Schlagel and Eisen Colliery

1. The Incident

A methane gas ignition occurred at 04:30 h on July 8, 1976 in Panel 4 of the Gustav Seam in the Schlagel and Eisen Colliery (Federal Republic of Germany). The initial ignition was caused by a shorted electrical circuit near the stage loader in the conveyor gateroad and extended for about 10 m along the roof of the gateroad. This ignition caused no appreciable damage, however, a fire was ignited between the anhydrite pack and the gateroad supports which caused repeated secondary ignitions at intervals as short as 3 to 5 seconds. All secondary ignitions took place between roadside supports and the anhydrite pack within 8 m of the inital ignition. Flame propagation was relatively slow (non-explosive) towards the face line. The site of the actual fire could not be determined accurately. No injuries occurred.

2. Background

The fire was located in the Gustav Seam workings, South District of the Colliery. No. 4 Panel (Figure 2) is a longwall face advancing downdip with the face pitching 8° to the southwest. The Gustav Seam is 1.9 m thick and the face length is 210 m. Both gateroads are supported by yielding steel arches on 0.75 m centres covered by wire mesh and brattice cloth. The intake gateroad has a foam-filled wood pack, while the conveyor gateroad is sealed off by a 1.3 m anhydrite pack.

The gateroads are maintained at a nominal cross-sectional area of 16 m^2. The fresh air supply is 1600 m^3/min at a pressure differential of 39 mm WG between face ends. Methane drainage holes are drilled into the roof and floor from the conveyor gateroad. These are connected to a collection range at 10 kPa below atmospheric pressure and produce, on average, 45 m^3/min. In spite of this methane drainage, the return air averages 1% CH_4 by volume with peaks up to 1.5%. Because of this high methane concentration, Panel No. 4 operates under an exemption from the Mine Regulations.

Panel production is 1600 t/day with an average face advance of 3.2 m/day. Ventilation flow is in the same direction as the coal transport; up the coal face at 8° and out along the conveyor gateroad.

The gate conveyor had been extended on the night of the accident. While the stage loader was being moved up, a cover plate caught the cable between the transformer and the switchgear and pulled it out of the transformer. The resulting spark caused the initial methane ignition.

3. Fire Fighting Procedures

The whole South District, comprising three longwall panels, was closed down and only mine rescue teams were allowed to carry out work in this area. The fire causing the secondary methane ignitions was thought to be either a gas bleeder burning like a bunsen burner or burning combustible material, (e.g. wood) behind the supports.

Neither possibility lent itself to conventional fire fighting procedures. Nevertheless, water from two ranges was injected into the hand stowed area behind the gateroad supports through 18 probes driven into the gob-side rib. As had been anticipated, there was no effect on the frequency of methane ignitions. However, it was felt that the cooling effect around the fire site would be beneficial.

In order to reduce the methane flow to the fire site a methane drainage hole was drilled from the relative safety of the face line. It was angled up into the roof strata over the fire. This borehole was connected to the methane drainage range in the early morning of July 9, producing 0.6 m^3/min of CH_4. This additional methane drainage was sufficient to increase the interval between ignitions to 5 - 6 hours.

The incombustible materials used in the support of the conveyor gateroad and the roadside pack showed their worth in this situation. After more than 24 hours of ignitions there was no detrimental effect on the supports. Had wooden lagging been used, the gateroad would probably have collapsed after this time interval.

Independent of the fire fighting activities, sealing the panel had been considered in the very early stages of the incident. Sites for the seals were selected and initial site preparation was carried out. However, sealing the panel was considered as a last resort.

4. Target Inerting With Nitrogen

Up to the time of this incident, six mine fires in Germany had been successfully extinguished by inerting into a sealed area. Because of the lengthy waiting period between inerting and reopening the district once sealed, the management decided to try "target inerting" for the first time. This method requires that the location of the fire be known, since the fire source needs to be flooded with nitrogen to extinguish the fire. Where extensive glowing embers are present this method will not put out the fire source.

Inerting had been considered since noon July 8. A propane fired nitrogen gasifier had been installed (capacity 100 m^3/min) along with two air gasifiers and liquid nitrogen storage. The delivery system for the nitrogen comprised:

- water range down the shaft,
- hose connection,
- water range along ventilation incline,
- hose connection through No. 3 Split,
- anhydrite pipeline along conveyor gateroad, and
- six nitrogen injection probes.

800 m of flexible inert gas hoses were used to connect the existing pipe ranges. Injection probes, made for such an application, were driven into the gob-side rib. At 08:00 h on July 9, nitrogen was delivered to the fire site at a rate of 50 m^3/min. This procedure gave the desired results with only one small ignition taking place after inerting was started. The nitrogen delivery rate was quickly reduced to 40 m^3/min and further reduced to 20 m^3/min on July 10. The roof and rib support between arches was removed under the protection of a continued nitrogen flow. No glowing embers of any kind were found so it was concluded that the ignition source must have been a gas bleeder.

Repair work continued in the gateroad with injection of nitrogen at the reduced rate of 20 m^3/min continuing until 08:00 h July 12. During inerting there was never an oxygen deficiency in the return air that could have been detrimental to human beings.

The face was restarted on the 23:00 H shift on July 12, 1976. A total of 126,000 m^3 of Nitrogen was used, at a cost excluding mine labour, of CDN $30,000.

The time schedule for the incident is shown on Figure 3.

Brzeszcze Mine (4)

1. Background

On April 21, 1978 a mine fire developed during blasting operations in Brezeszce Coal Mine, Poland, in the gassy 352 seam. Attempts to extinguish the fire by use of active means failed and the area had to be sealed off. The fire area, whose volume was estimated to be 150,000 m^3 was ventilated during the construction of gypsum fire dams 1,2,3, and 4 (Figure 4).

2. Inert Gas Supply and Distribution

A CMI (GAG) inert gas generating unit was installed ahead of fire dam 1.

3. Operational Procedure

The fire dams were constructed and the CMI inert gas generator installed. The CMI unit was run for 4½ hours, inerting the gases in the fire area and allowing the safe closing of dams 2 and 3. The volume of inert gas fed into the area was 330,000 m^3. With the fire area sealed and inerted the fire was extinguished. However, the temperature inside the fire area was too high to open the fire dams, so a system for recirculation and cooling of the fire gases was installed (Figure 5).

A plugged duct section (800 mm dia) provided in dam 1 and a plugged duct section (300 mm dia) in dam 3 were prepared for connection with the duct line for recirculation of the combustible gases. The duct line contained for following elements:

- two water coolers equipped with water jets and a drain water trap.
- a control gate for control of gas flow rate to the cooling capacity of the system,
- a booster fan for recirculation of inerted fire gases,
- gas sampling point, and
- temperature and flowrate measurement.

The gases in the fire area, both beyond dam 1 and outlet dams 2,3, and 4 had been inerted by application of the CMI unit and contained 5% O_2 and above 80% CH_4.

In order to start the recirculation of inert gases and the cooling of the fire area, the following procedure was followed:

- the gates in the ductline were opened and gases from the fire area were introduced into the ductline simultaneously with starting of the cooling system,
- the control gate opened the ductline up to half of its cross section, and
- the booster fan was started and the flowrate of gases adjusted.

The temperature of the recirculated gases dropped from 120°C to 35°C. It was then necessary to reventilate the fire zone to remove the high concentration of methane. The methane drainage system for the area was started and a recirculation system installed for ventilating the area without opening the dams (Figure 6). A gas hazard zone was established. All men were withdrawn and electric power disconnected.

The reventilation procedure was as follows:
- ductline in dam 1 and 3 were closed,
- a duct section was removed directly beyond the auxiliary fan,
- air flowrate of 1200 m^3/min was maintained in incline drift where the auxiliary fan was located, and
- the auxiliary fan was turned on and the ductline gates opened.

The fire area was then ventilated at a rate of 400 m^3/min for a period of 25 minutes. After a further 4 hours, dams 1,2, and 3 were opened and mining operations restarted in the area.

4. Comments

This case study demonstrates how the use of the CMI inert gas generator allowed safe sealing of a methane fire. The methods used for cooling and reventilating the fire zone allowed rapid resumption of production.

L'Herault Mine (5)

1. Background

This case study describes a fire during the development of the L'Herault underground uranium property in the Mas Lavayre in France.

At the time of the incident, two declines were being driven. The one in which the fire took place had a gradient of approximately 14° with a cross section 2.5 m high by 4 m wide. The drift, which had advanced some 700 m, was not connected to any other workings and was equipped with a belt conveyor whose drive head was located on the surface.

The incident occured at 5 am at the start of the first shift of the day. At 5:15 am a workman noticed that the drive head was glowing and that the slipping driving drum had started a fire on the conveyor belting. The workman stopped the motors, tried to deal with the fire using extinguishers without success and raised the alarm. At this moment, the belting broke and the top belt ran down into the underground workings. A warning was given immediately by telephone to the men underground at 5:15 am. Senior staff arrived on the site by 5:30 am and an appreciation of the situation was made.

All the workmen on the shift made their way back to the surface having attempted to put the fire out using extinguishers from along the decline. The fire area was about 70 m from the surface. The belt was piled up in an accordion fashion, resting on the structure, leaving space alongside for the workmen to escape. The auxiliary ventilation had been stopped.

Black smoke was coming out of the top of the portal and fresh air was entering at floor level. The fire appeared to be getting worse. It was considered critical to save as much as possible of the conveyor system and to re-establish pumping as soon as practicable to prevent damage to the motors on the equipment at the bottom of the drift.

The injection of inert gas would eliminate oxygen and purge the atmosphere in the decline so that recovery operations could be carried out, and would have a beneficial effect on the temperature. It was decided to use carbon dioxide because it was available in large quantities, could be transported in a liquid form, and by virtue of its density would progressively fill up from the bottom of the 14° decline to the surface, creating an atmosphere high in CO_2 and thus inert the fire. The low temperature of the gas would assist cooling.

2. Carbon Dioxide Supply and Distribution

Carboxyque Francais supplied a 30-ton truck of liquid CO_2 by 8 pm. The liquid CO_2 was pumped through a stopping erected at the portal into the decline.

3. Operational Procedure

The CO_2 was pumped into the decline from 9:00 pm until 5:30 am when the truck was empty, at an average rate of 66 m^3/min. The CO concentration at the stopping reduced from several hundred ppm initially to almost zero at the end of injection. CO_2 concentrations at the stopping did not increase for a considerable time, indicating it was filling the decline from the bottom.

The next morning, a reconnaissance by two rescue teams from the Cevennes Coalfield in the vicinity of the stopping indicated an absence of oxygen in the decline, that the fumes had been cleared, a reasonable ambient temperature and a high concentration of CO_2. No dangerous concentrations of CO were discovered. A second examination found the conveyor belt still red for a length of 6 to 10 m. It was

extinguished using water hoses. At 10 pm the ventilation was put back into action to supply fresh air and clear the CO_2 out of the drivage. The next morning an investigation by the rescue team conducted throughout the length of the 700 m gallery confirmed that the atmosphere was respirable. Pumping began and the incident was closed.

4. Comments

The carbon dioxide had no negative effects on the drivage or its equipment. Risks to the rescue personnel were reduced and the cost of the stoppage of the drivage was minimized by the rapid control of the fire by this inerting technique.

CONCLUSIONS

Underground mine fire control with inerting systems is a proven mature technology that should be considered by the Canadian mining industry. The preferred inerting technique will vary depending upon numerous site specific factors. Inerting is not a panacea or subsitute for conventional fire fighting and control methods but is a valuable addition to the range of techniques that can be applied to underground mine fires.

Training should stress that inerting is only one of many available techniques and should emphasize the need for extensive prior preparations including discussions with potential inerting suppliers/ contractors.

High risk mines (coal and other gassy mines) in particular should include inerting consideration in their emergency management planning. In West Germany coal mine rescue personnel now prefer to operate within an oxygen deficient environment rather than run the risk of secondary gas explosions during direct fire fighting. The West German central mine rescue service recommends that nitrogen inerting mobilization be undertaken at the initial stages of all mine fires. They also operate with the motto "When in doubt, inert!"

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Table 1 - Advantages/disadvantages of inerting media

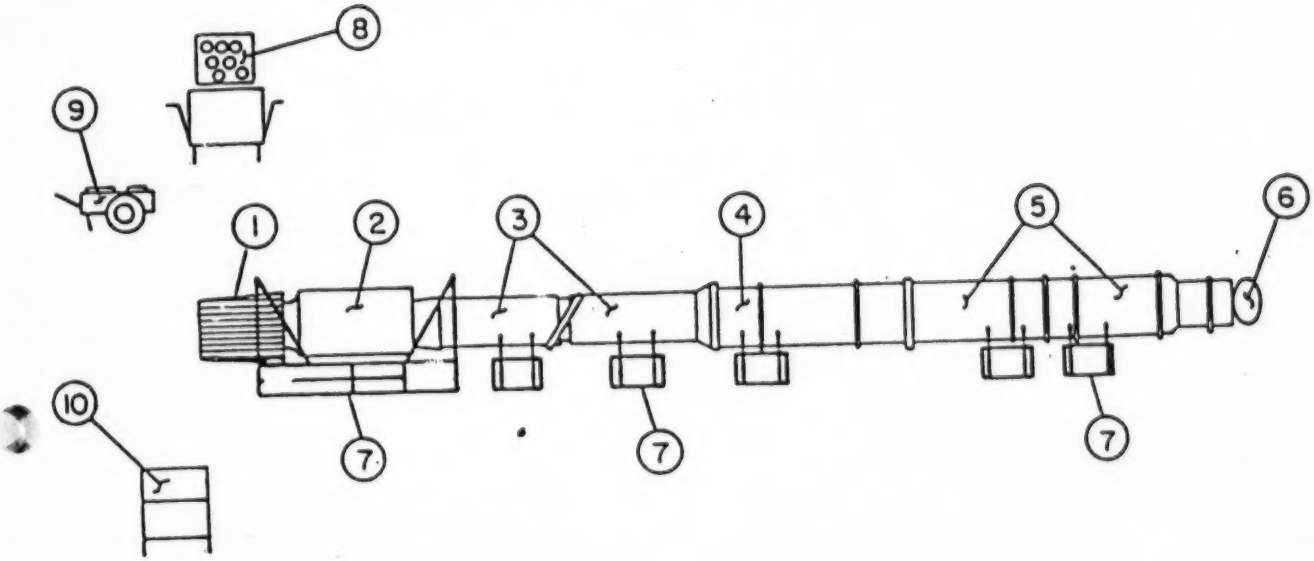
Inerting Media	Advantages	Disadvantages
GCP (gaseous combustion products generated by inert gas generator)	- generated on site; independent of commercial suppliers - cheap relative to other inerting media - capable of high rates of inert gas production (up to 1800 m^3/min) - can be operational within two hours of delivery to site - carries large water volume into fire zone to aid in cooling - can maintain ventilation to fire zone due to high rate of inert gas production	- requires large fuel, water and fresh air supply to unit - products vary in concentration and include typical undesirable combustion products - product contains 1 - 3% oxygen - products delivered into fire zone at a relatively high temperature (up to 90°C) - products cannot be transported long distances without secondary blowers - high water content can lead to hydrogen production at fire site - can upset ventilation pressure distribution in mine - does not comply with flameproof coal mine requirements - interferes with fire status and trend interpretation by contributing combustion products to the fire zone
Carbon Dioxide	- readily available in commercial quantities as liquid or solid that can be stored and transported - is an extinctive gas - can be evaporated in commercial mobile plants - can be delivered at low temperatures to the fire zone to promote cooling - higher density than air; good for fires located in depressions and sinking workings	- more expensive than GCP or nitrogen - can be highly reactive: corrosive in steel pipes in the presence of water, can be reduced to CO by hot carbon - interferes with CO_2 fire status and trend interpretation monitoring - makes explosibility prediction difficult - rate of delivery to fire zone in gaseous form limited by capacity of evaporation unit - density higher than air: tends to pool in depressions, not follow ventilation path
Nitrogen	- stable, inert, non-reactive and extinctive - readily available in commercial quantities that can be stored and transported - does not interfere with fire status and trend interpretation or complicate explosibility prediction - density close to air - can be evaporated in commercial mobile plants - can be delivered at low temperatures to the fire zone to promote cooling	- subject to evaporation losses when stored, expensive to stock - more expensive than GCP but cheaper than carbon dioxide - rate of delivery to fire zone in gaseous form limited by capacity of evaporation unit

Table 2 - Inert gas generators

Parameters	GIG-50*	GIG-4*	GIG-1500*	GAG-2**	GAG-3+
Productivity, m^3/min	50-120	340	800-1500	720-1500	850-1870
Oxygen content, % vol.	2-3	1-2	1-2	1	1
Fuel consumption, kg/h	260	820	3400	2880	1080++
Water consumption, m^3/h	8	27	50	30	69
Dimensions, m					
Length	4.0	6.5	11.2	11.9	15.0
Height	0.7	0.8	1.0	1.0	0.9
Width	0.7	0.9	1.1	1.1	1.1
Supply voltage, V	280/660	Self-powered	Self-powered	24	24

* Source: Khudosovtsev and Kozlyuk
** Source: Villedent
\+ Source: Kopex brochure
++ Value provided in Kopex brochure appears anomalous

Figure 1 - Inert gas generator gag



1. Air filter (1 m x 1.2 m)
2. Engine (1.1 m x 1.5 m)
3. Afterburner (.9 m x 2.7 m)
4. Cooling chamber (1 m x 2.3 m)
5. Ductwork (1 m x 3.2 m)
6. Fire dam door (shown open)
7. Skids
8. Control console
9. Battery cart
10. Fuel tank and pump

Figure 2 - Gustav seam no. 4 panel plan

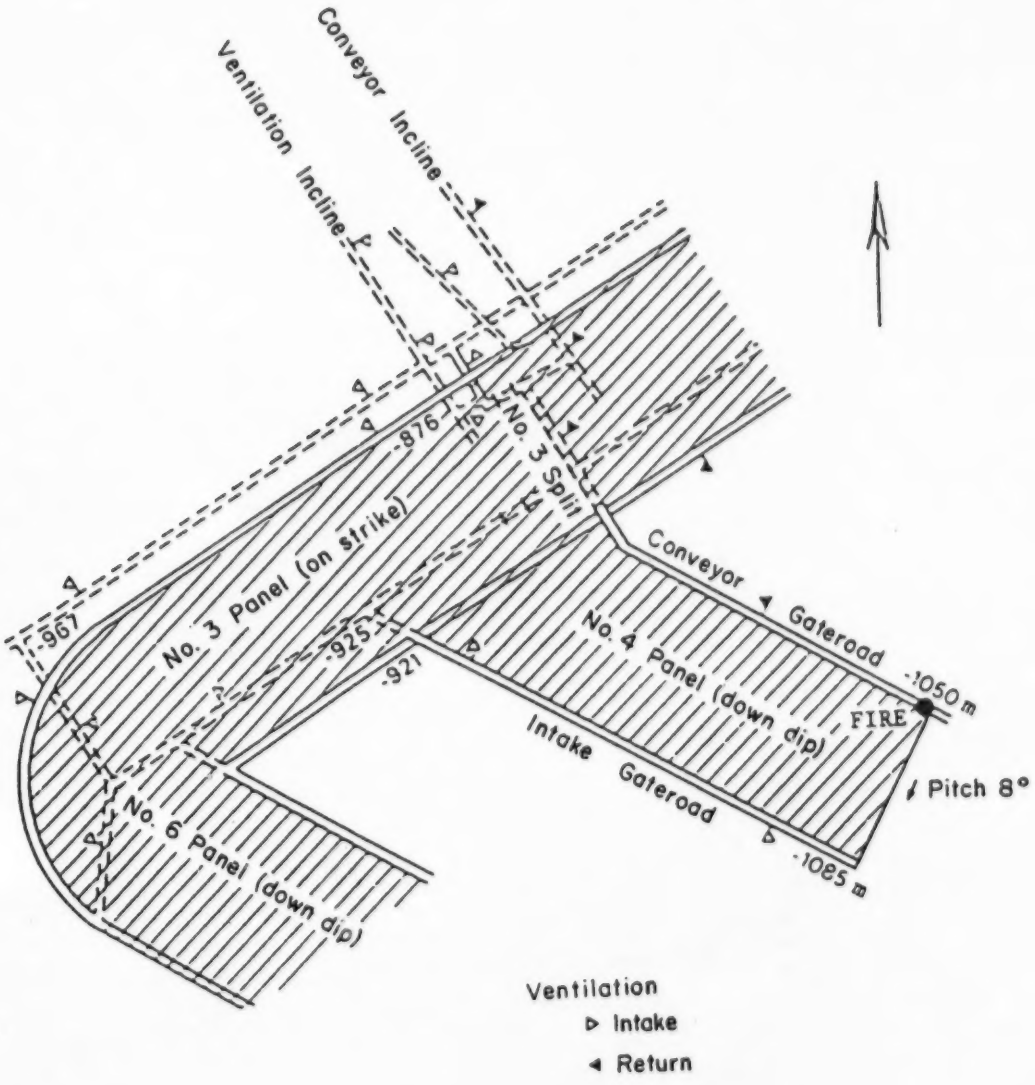


Figure 3 - Time schedule

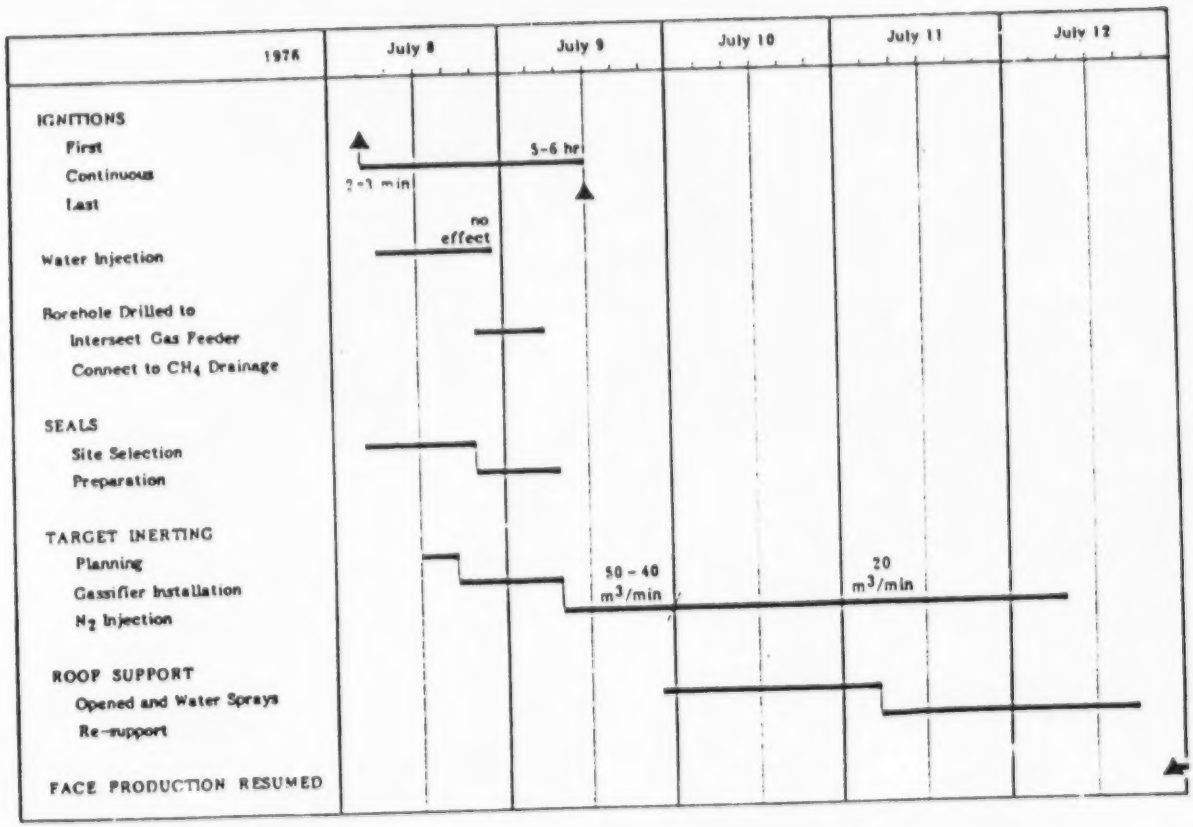
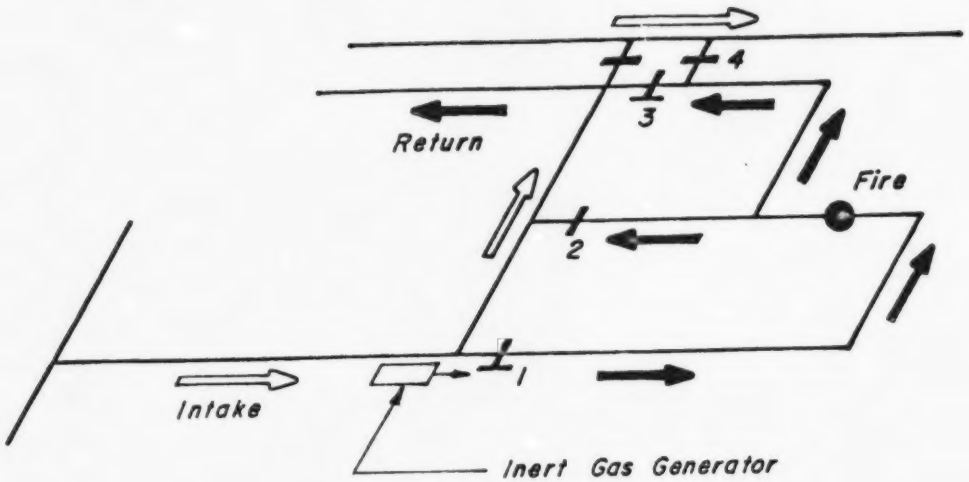


Figure 4 - Ventilation scheme during fire fighting operation

Brzeszcze Mine



— full dam

⊥ dam with door

Figure 5 - Cooling the fire zone

Brzeszcze Mine

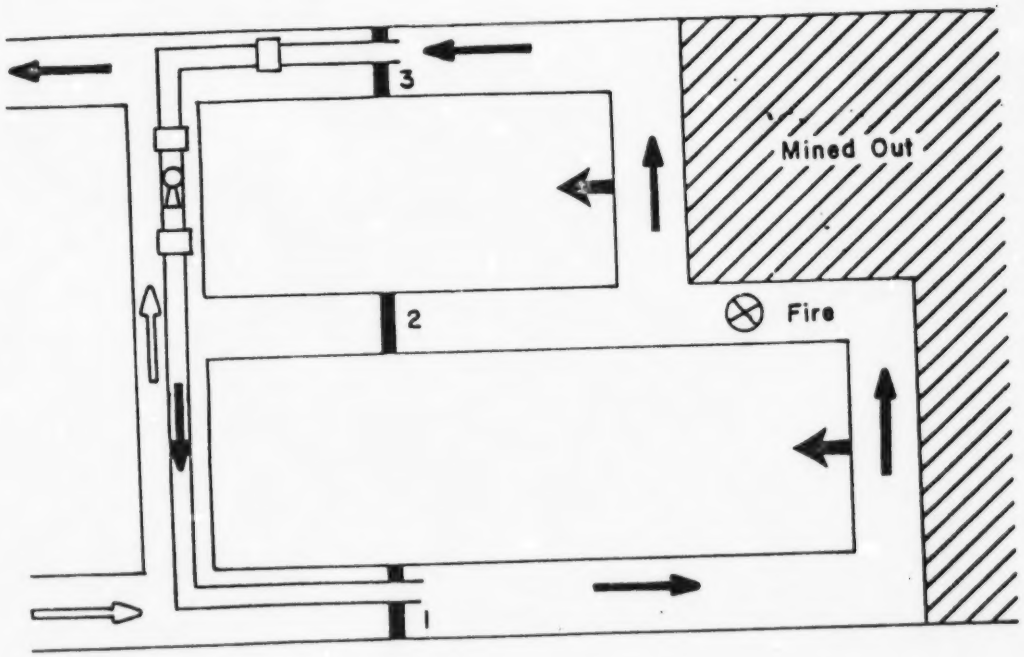
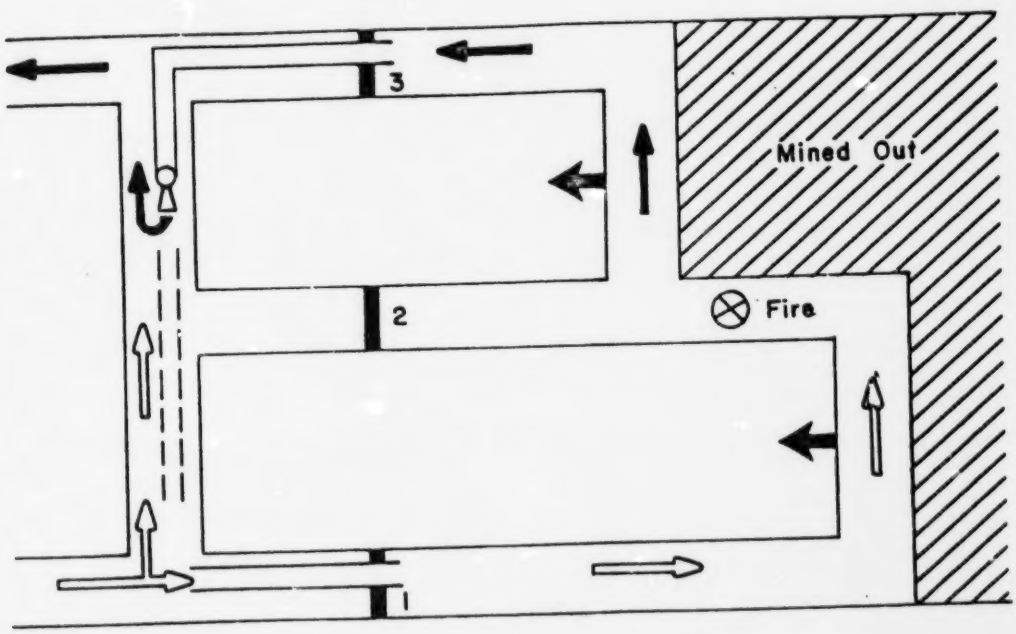


Figure 6 - Reventilation of the sealed zone

Brzeszcze Mine